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PHYSIOLOGY OF PADDY RICE CULTIVATION

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This report contains information on Chinese agricultural techniques, focusing on the physiology of paddy rice cultivation. This includes the life cycle of paddy rice, seed germination, tillering, growth characteristics, and fertilizer application.

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PHYSIOLOGY OF PADDY RICE CULTIVATION

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[Text] Editor's Note

The topic concerning the physiology of cultivation was discussed as early as the 1960's in our nation. It studies certain important physiological functions and their patterns of change throughout the growth and development of the whole plant during the cultivation of the crops. These functions mainly include the physiological bases for high yield and superior quality, growth habits and ways of controlling them, measures for cultivation (such as reasonable application of fertilizers, scientific use of water, reasonably dense planting, etc.) and the actual physiological nature of measures to increase production as well as related physiological questions concerned with resisting adverse external conditions. The physiology of cultivation is the direct theoretical basis of the cultivation of crops, the connecting point between plant physiology and the science of crop cultivation, and is also the science of reasonable arrangement of measures of cultivation, of controlling growth and development of agricultural crops, and of establishing crop cultivation techniques upon a reliable physiological foundation.

Our nation has a long history of paddy rice cultivation and we possess a wealth of experience. Since Liberation, many achievements have been made in scientific experiments in paddy rice physiology. To realize the "four modernizations" by the end of this century as brought out by the great leader and teacher Chairman Mao and his will that "in the future, China must become the top producing nation in the world," and to carry out the strategic policy of "grasping the key link in ruling the nation" brought out by the wise leader Chairman Hua, we have attempted to compile this book entitled "Physiology of Paddy Rice Cultivation" according to the need for scientific research and as an attempt to adapt paddy rice production and popularization of Dazhai County in the movement to learn from Dazhai in agriculture. The content has been arranged so that the first half of the book describes the growth habits of paddy rice and the means of controlling them according to the several major stages of growth and development of the paddy rice plant so as to establish the physiological foundation for high yields and superior quality. The latter half of this book describes the physiological foundation of several measures of cultivation (utilization of varieties, reasonable application of fertilizers, management of irrigation and muddiness of the field, reasonably dense planting) according to Chairman Mao's "eight point charter" for agriculture. In writing this book we have emphasized some major problems in production that affect the yield during the cultivation of paddy rice in the middle and lower

reaches of the Chang Jiang and effective measures of cultivation. Some resource material at home and from abroad have been used in the physiological analysis to attempt to find some inspiration for solving these problems of production. Thus, actual measures of cultivation are described in rather general terms and in principle only. In addition, the last part of the book also contains 15 commonly used experiments in the physiology of paddy rice cultivation (totaling 26 methods). Since compiling and writing "The Physiology of Paddy Rice Cultivation" is a first attempt and because of the limited scope of knowledge of the writers and compilers, there are surely mistakes and inadequacies which we respectfully hope readers will point out to us so that this book can be written more perfectly.

The following persons have contributed to the writing and compilation of this book: Comrades, Huang Xianghui [7806 4362 6540], Hu Maoxing [5170 5399 5281], Wu Jiren [0702 0679 0088], Guan Heyi [4619 0735 0110] and Zhang Zhiliang [1728 1807 5328]. During the course of writing this book we received assistance from the Zhejiang Academy of Agricultural Sciences, Zhejiang Agricultural University, Jiangsu Academy of Agricultural Sciences, Central China (Huazhong) Agricultural College,

Jiangsu Provincial Yixing May 7 Agricultural University, Wuhan University's Biology Department, Hunan Teacher's College's Biology Department, Hunan Provincial Paddy Rice Institute, the Shanghai Plant Physiology Institute of the Chinese Academy of Sciences, and the Shanghai Municipal Academy of Agricultural Sciences which provided valuable information and opinions. Sincere thanks are hereby given.

February, 1978

Foreword

The great leader and teacher Chairman Mao taught us: "One is food and other is steel. With these two things, everything else will be simple." Agriculture is the foundation of the national economy. Grain is the basis of that foundation. Grain not only affects people's lives, it also affects the development of the entire national economy and the solidarity of proletarian dictatorship. Only by resolutely taking class struggle as the key link and grasping revolution and promoting production so that bumper harvests of grain can be realized year after year can we obtain food, be relieved from fear, stand on solid ground and be provided with happiness. Paddy rice is an important grain crop in our nation. It carries a heavy weight in our nation's grain production. In area of cultivation and in total production, it occupies first place among all grain crops. Statistics show our nation's paddy rice fields cover an area equivalent to one third of the area of all grain crops of the nation. Total yield of paddy rice constitutes half the total production of grain crops. Therefore, developing paddy rice production is extremely important in increasing the production of grain and in realizing Chairman Mao's great strategic policy to "be prepared against war, be prepared against natural disasters, do everything for the people" and "dig tunnels deep, store grain everywhere and never seek hegemony."

Paddy rice occupies such an important position in our nation's grain crop production because it possesses the following characteristics:

--There are many types of paddy rice. The xian and geng types are adaptive to geographical location and elevation. There are the early, intermediate and late types of rice that are adaptive to different openings in crop rotation and different planting systems. Each type of rice possesses its early, intermediate and late maturing varieties. Thus, paddy rice has a wide adaptability. Paddy rice is widely distributed in our nation, east from Taiwan Province and its outlying islands and west to Xinjiang, south from the tropical zone's Hainan Island and its outlying islands to the northernmost places of Heilongjiang Province in the temperature zone. It is planted on river banks and in coastal regions and in the Yunnan Highlands 2500 meters above sea level (the highest elevation for planting paddy rice in the world today).

--Paddy rice is an irrigated crop. Irrigation can regulate fertility, aeration, temperatures and stimulate or control growth and development of paddy rice easily. Thus, paddy rice has a relatively stable, high yield.

Because paddy rice yields a greater number of panicles per unit area, each panicle has a greater number of grains, the "ratio of grain to plant" (the ratio of the weight of the grains to the weight of the rest of the plant at final harvest) is high and the percentage of utilization of fertilizers is high, it has better surplus yields.

—Rice possesses a rich nutritional value. In general, it contains an average of 75 percent to 79 percent hydrocarbons, 6.5 percent to 9 percent protein, 0.2 percent to 2 percent fat, 0.2 percent to 1 percent fiber and 0.4 percent to 1.5 percent ash. It contains the least amount of crude fiber. Although rice has a low protein content, its biological value (the numerical value of absorbed protein as a portion of the total amount of protein constituted in the adult human body) is comparable to that of soybeans. At the same time, the percentage of digestible and absorbable contents is high. Therefore rice and wheat serve equally as the major food grains for people.

--Also paddy rice has a strong resistance to adversity. Paddy rice can be planted in low marshlands and saline and alkali soils where other crops cannot adapt to fully. Planting paddy rice to improve the soil is also a means to further plans and construction of water conservancy projects for farmland. Thus, the development of paddy rice production is extremely significant to our nation's socialist revolution and construction.

China is not only the world's oldest nation but also one of the world's original places to cultivate paddy rice. The mass of rice grains, rice husks and rice stalks dug up at the Neolithic site at Hemudu in Yuyao County, Zhejiang Province, and the large number of bone ploughs (tool for turning the soil over) show paddy rice has been cultivated in China for more than 6000 to 7000 years (Wood excavated from that cultural layer determined by C^{14} was 6310 ± 100 years old and the annual rings of tree trunks showed a corrected age of 6960 ± 100 years old). The site's carbonized rice grains were determined to be cultivated paddy rice of the last xian type of the xian subspecies. Its scientific name is Oryza Sativa L. Subsp xian Ding. This discovery coupled with the abundance of undomesticated wild rice (xian type) throughout southern China is sufficient proof that China was one of the world's origins of paddy rice cultivation.

Over several thousand years of actual production, our nation's laboring people have accumulated a rich experience in paddy rice cultivation. Many superior varieties have been cultivated and many ancient agricultural texts have systematized and theorized the experience of paddy rice cultivation, such as the "Book of Si Sheng" written over 2000 years ago, the "Qi Min Yao Shu" written over 1400 years ago and the "Tien Gong Kai Wu" of the latter part of the Ming dynasty. These have been the more outstanding texts which have served to create favorable conditions for producing high yields of paddy rice in China.

But prior to Liberation, due to the cruel exploitation and suppression by imperialism, feudalism and bureaucratic capitalism, the production of paddy rice like production of other agricultural crops in our nation was seriously

abused and destroyed. Over a long period, the area of paddy rice could not be expanded. Unit area production stagnated. Nobody cared about the scientific research of paddy rice. Rice production was not self sufficient and "foreign rice" had to be imported from abroad each year.

After the founding of New China and under the wise leadership of Chairman Mao and the Party Central, land reform, cooperation of agriculture and establishment of people's communes were accomplished. The great victory of transforming our nation's farm village society greatly liberated the productive forces. The superior socialist system and collective economy's great power pushed forward our nation's production and scientific research of paddy rice. The broad masses of the poor and lower-middle peastants followed the "Eight Point Charter" for agriculture brought out by Chairman Mao and engaged in scientific planting for the revolution. The area of paddy rice cultivation continuously expanded and yields rose continuously. As early as the end of the 1950s and the beginning of the 1960s, we gradually realized the development of dwarfed superior varieties of paddy rice and pushed our nation's paddy rice production further forward.

The Proletarian Cultural Revolution personally launched and led by Chairman Mao crushed the three bourgeois command headquarters of Liu Shaoqi, Lin Biao and the "gang of four," greatly heightened the broad masses of awareness, of class struggle and the struggle between the lines and stimulated their enthusiasm towards increasing production of grain. The broad masses of poor and lower-middle peasants, revolutionary cadres and scientific and technical personnel joined together to conscientiously study Marxism-Leninism and Mao Zhedong Thought, launched the movement to "learn from Dazhai in agriculture" in a profound way, and rapidly developed our nation's paddy rice production and scientific research. At the beginning of the 1970s, our nation's per unit output of paddy rice had already greatly surpassed the world's average. In our nation's southern paddy rice region, the advanced unit of Yancuo Brigade in Minhou County, Fujian Province, produced 2000 jin of paddy rice per mu continuously for 8 years, and in the northern paddy rice region where the frostfree period lasts only 150 to 160 days, the advanced unit of Shuiyuan Brigade in Yingou County, Liaoning Province, produced over 1000 jin per mu in normal years continuously for 5 years.

Following the rapid development in paddy rice production, new topics and a new outlook in the development of the physiology of our nation's paddy rice cultivation emerged. The development of the triple cropping system following reform of the planting system especially in the middle and lower reaches of the Yangtze River area greatly increased grain production. But at the same time a series of problems and contradictions concerning combinations of varieties with different growth periods, the problem of rotting seedlings and assuring healthy seedlings in seedling cultivation of high-yielding early rice, low temperature damge during early rice's young panicle differentiation and oppressive heat caused by high temperatures during the latter growth period of early rice, the problem of "raised panicle heads" of late season rice and adaptability to mechanization emerged. Due to the alliance of the broad masses of scientific personnel and the poor and lower-middle peastants, progress has

been made jointly in theory and practice in recent years in many important subjects of research such as solving the problem of rotting seedlings and dying sprouts, overly early germination and maturation of paddy rice transplanted by machine, proper fertilization and irrigation, diagnosis of nutrients, avoidance of high and low temperature damage, reduction of the percentage of empty and semi-filled grains and prevention of "raised panicle heads."

Especially encouraging is that, under the personal care and guidance of the wise leader Chairman Hua Guofeng, our nation successfully bred hybrid rice in 1973 and realized the application of heterosis in paddy rice production.

The success in the cultivation, propagation and use of hybrid rice was an important breakthrough in the work on seeds and another great technological renovation in our nation's paddy rice production. It not only opened a new path in turning low yields into high yields and high yields into higher yields of paddy rice production in China, but also a new arena for studying the physiology of paddy rice cultivation in our nation. Over the past several years, preliminary and encouraging results have been achieved in solving such physiological problems concerning differences in flowering periods, raising the percentage of cross pollination and in the study of physiological foundation of heterosis of paddy rice.

The revolution is continuing and production is developing. Although, under the guidance of the revolutionary line of Chairman Mao, our nation's paddy rice production and scientific research have achieved definite results, further battles must be waged conscientiously when such achievements are considered within the framework of the general situation of the rapidly leaping development of the entire socialist revolution and construction. We believe that under the leadership of the Party Central headed by the wise leader Chairman Hua and under the great call of Chairman Hua to "grasp the key link in managing the nation," our nation's paddy rice production and scientific research will develop more rapidly so that where there is discovery there is invention and where there is creation there is progress and that new contributions can be realized for the Revolution in China and World Revolution.

CHAPTER 1. LIFE CYCLE OF PADDY RICE AND FORMATION OF YIELD

The life of paddy rice begins when the seeds germinate and grow through various stages until formation of new seeds. This constitutes the life cycle of paddy rice. During its life, a series of changes in the plant's shape, structure, physiology and biochemistry takes place. To understand and recognize the pattern of these changes, the life cycle of paddy rice is divided into several stages according to the characteristics of growth and development.

The yield of paddy rice consists of three elements, the number of panicles per mu, the number of grains per panicle and the weight of grains. These three elements are formed in succession during the growth process. Therefore, we must understand the nature of development by stages in the formation of yield of paddy rice and the mutual relationship among the stages so that proper measures can be taken before hand to bring about certain desirable effects afterwards and realize higher yields of paddy rice.

I. The Life Cycle of Paddy Rice

In the life cycle of paddy rice there are two growth stages which are vastly different yet mutually related. They are the vegetative growth stage and the reproductive growth stage. The vegetative growth stage refers to the period from the time of germination of the seed to the time prior to the beginning of differentiation of the young panicles. The major activities during the vegetative growth stage are the formation of vegetative organs, growth of roots, growth of leaves and growth of tillers. It is also the period in which the plant accumulates organic substances within the body to build the foundation of material supplies for the reproductive growth stage. The reproductive growth stage begins from differentiation of young panicles to formation of new seeds, mainly the formation of reproductive organs, growth of the stalk, panicles, flowers, filling, fruiting.

The vegetative growth stage can be divided into two growth periods, the seedling stage and the tillering stage. The seedling stage refers mainly to the period of seedling cultivation in seedbeds. The tillering stage is further divided into greening stage, effective tillering stage and ineffective tillering stage. After transplanting, the plant undergoes a period in which the seedling stops growing and new roots emerge, generally 3 to 5 days; this is called the greening stage. After greening, tillering begins. This is called the beginning tillering stage. During this stage, the tillering speed is slow. Later, as the plant's assimilative function becomes stronger and growth

becomes more prosperous, the speed of tillering suddenly increases. The period in which tillering occurs the fastest is called the vigorous tillering period. After this period, tillering slows down gradually until jointing. Tillers cease to emerge in general when jointing is about to begin or after jointing begins. This period is called the latter tillering period. The period in which tillering occurs most abundantly is called the peak tillering period. There are two types of paddy rice tillers. One type is the effective tiller and the other is the ineffective tiller. Under normal conditions, the majority of tillers that emerge early, for example, when there are already three leaves and a strong root system, and grow to become panicles are effective tillers. Tillers that emerge within 15 days from jointing that are comparatively small and mostly die afterwards are ineffective tillers. Thus, taking 15 days prior to jointing as the demarcation, the effective tillering stage is the period from the beginning of tillering to 15 days prior to jointing. The period from 15 days prior to jointing to the time of jointing is the ineffective tillering stage.

The reproductive growth stage includes the periods of panicle growth and fruiting. The period of panicle growth begins from differentiation of young panicles and ends at heading. According to the degree of development of differentiation of the young panicles, the period of panicle growth is further divided into the period of branch and stalk differentiation, spikelet differentiation, pollen mother cell meiosis and formation of the pollen grain. Under normal conditions, the panicle growth stage lasts around 30 days. The fruiting stage begins from heading and ends at maturity. According to the degree of filling of the endosperm, this stage can be further divided into the milky ripe period, waxy ripe period and completely ripe period. Duration of the fruiting period varies according to variety, climate and planting conditions. In general, the fruiting stage of early rice lasts between 25 and 30 days, that of intermediate rice lasts between 35 and 40 days and that of late rice lasts about 45 days.

Although the vegetative growth stage and the reproductive growth stages are often differentiated by the beginning of differentiation of young panicles, in actuality the two stages are very difficult to separate. They are closely connected and they affect each other, limit each other and infiltrate each other. Although during the vegetative growth stage the growth of reproductive organs cannot be observed in form, material changes for the formation of young panicles do take place physiologically. At the same time, whether the vegetative growth is good or bad directly affects reproductive growth and the formation of yield. Although the major activity during the reproductive growth stage is the formation of panicles, flowers and seeds, it is also accompanied by growth of stalks (jointing, heading), leaves and roots. During this stage, the condition of vegetative growth also affects yield to a large degree. Early withering of vegetative organs (such as overly early wilting and yellowing of leaves or decrease in their function), remaining green (when growth is overly prosperous and causes late maturation) are all unfavorable to reproductive growth.

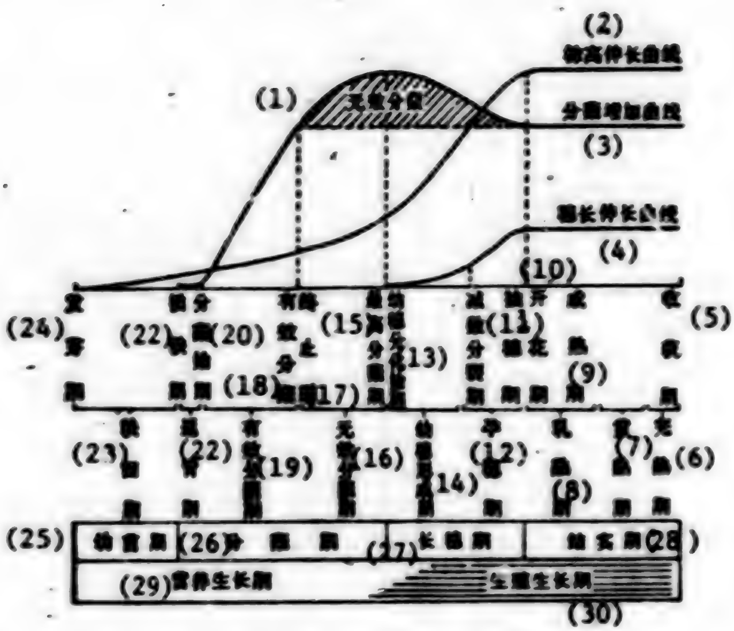


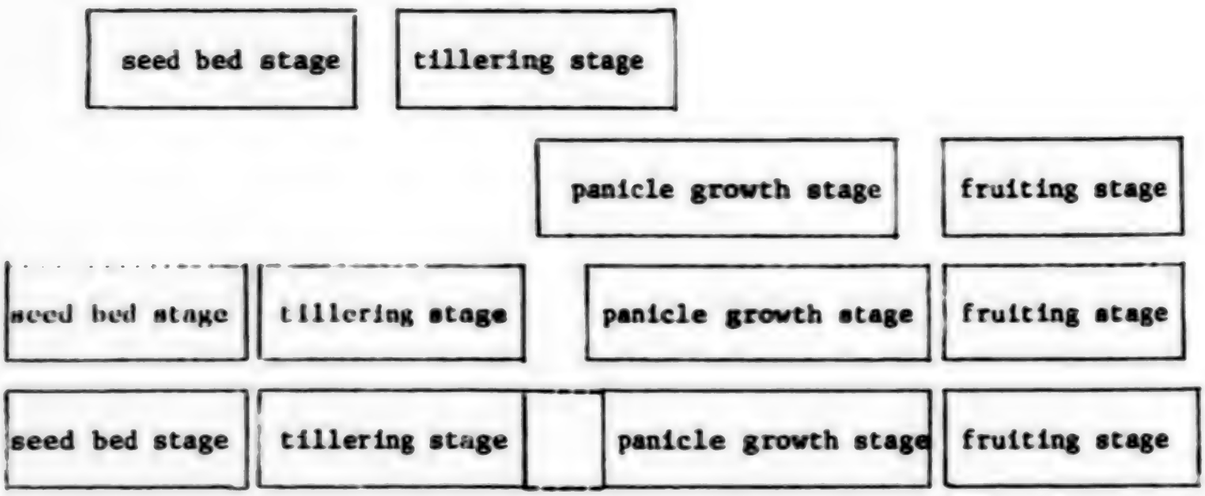
Diagram 1. The Life Cycle of Paddy Rice

Key:
(1) Ineffective tillers
(2) Plant height curve
(3) Curve of increasing tillers
(4) Panicle length extension curve
(5) Harvesting stage
(6) Completely ripe stage
(7) Yellow ripe stage
(8) Milky ripe stage
(9) Maturity stage
(10) Flowering stage
(11) Heading stage
(12) Panicle bearing stage
(13) meiosis
(14) Young panicle forming stage
(15) Young panicle differentiation beginning stage
(16) Ineffective tillering stage
(17) Peak tillering stage
(18) Effective tillering ending stage
(19) Effective tillering stage
(20) Beginning tillering stage
(21) Greening stage
(22) Transplanting stage
(23) Seed bed stage
(24) Germination stage
(25) Young seedling stage
(26) Tillering stage
(27) Panicle growth stage
(28) Fruiting stage
(29) Vegetative growth stage
(30) Reproductive growth stage

I. Types of Growth of Paddy Rice

The growth of paddy rice includes vegetative growth and reproductive growth but in actuality these two stages are inseparable. The tillering period of the vegetative growth stage ends when jointing begins while the panicle growth period of reproductive growth stage begins when young panicles begin to differentiate. Young panicle differentiation and jointing are closely related.

In general, panicle differentiation begins when the reverse 5th internode (the reverse 1st internode is the internode between the node of the panicle neck and the node from which the boot leaf extends, and counting downward are the reverse 2nd node, reverse 3rd node...) is about to extend. Thus the tillering stage and panicle growth stage may overlap, connect with each other and separate from each other (Diagram 2). These form the different types of growth of paddy rice.



Top: Overlapped Type Varieties with 4 or less elongating internodes

Middle: Connected Type Varieties with 5 elongating internodes

Bottom: Separated Type Varieties with 6 or more elongating internodes

Diagram 2. Three Types of Growth of Paddy Rice

A. Overlapped Type

These types of varieties have 4 elongating internodes above ground. When the internode (i.e., reverse 4th internode) at the base of the main stem elongates, the young panicles have already begun to differentiate. In other words, the young panicles begin to differentiate early and tillering ends late. Therefore, the tillering period and panicle growth period overlap for about one week. Ordinary early rice varieties (such as Er jiu qing, Ai nan zao No 39) are of this type.

B. Connected Type

These types of varieties have 5 elongating internodes above ground. When the internode (i.e., reverse 5th internode) at the base of the main stem elongates, the young panicles are just beginning to differentiate. Jointing and young panicle differentiation begin at the same time. The end of tillering is the time the young panicle begins to differentiate. Therefore, the tillering period and the panicle growth period are connected. Ordinary intermediate rice varieties (such as Nongken 57, etc.) are of this type. There are also exceptions such as the intermediate geng "Guihuahuang" variety which has 6 to 7 elongating internodes above ground and belongs to the separated type.

C. Separated Type

These types of varieties have elongating internodes above ground. When the internode (i.e., reverse 6th internode) at the base of the main stem elongates, young panicles have not begun to differentiate. Jointing occurs before young panicles begin to differentiate. In other words, tillering has already stopped but the young panicles have not begun to differentiate. Therefore the tillering period and the panicle growth period are separate. Ordinary single crop rice varieties (such as Sugeng No 2, Nonghu No 6) are of this type.

However, the growth types of varieties are not permanent and unchangeable. When planting and cultivation seasons or the locality of planting cause the growth period to extend visibly, the overlapping type may be transformed into the connecting type and the connecting type may be transformed into the separated type. Conversely, when the growth period is shortened visibly, reverse changes may occur; the separated type may be transformed into the overlapping type. For example, "Huxuan 19" variety planted as single crop late rice has 6 elongating internodes above ground and is of the separated type. Planted as a double crop late crop rice, it has 5 elongating internodes above ground and is of the connecting type.

In production, the method of cultivation varies according to the different types of growth. For example, young panicle differentiation of early rice will have already begun at the time of tillering. Therefore fertilizers for tillering must be applied early and heavily and fertilizers for growth of panicles will not be needed in general. Single crop late rice's young panicles begin to differentiate after tillering has already stopped, thus the application of fertilizers for panicle growth is extremely important.

III. Formation of Paddy Rice Yield

The yield of paddy rice consists of the number of panicles per mu, the number of grains per panicle and the weight of grains. Because different organs grow during different stages of growth, their effect upon yield is also different and the measures taken are also different. These are explained as follows:

A. Seed Bed Stage

The seed bed stage is the fundamental period to assure high yield. The quality of the seedlings, whether good or bad, greatly affects the formation of the number of panicles, the number of grains and the weight of the grains. It must not be overlooked. In recent years, after the area of double crop rice was expanded and the planting system of triple cropping a year was implemented in the middle and lower reaches of the Chang Jiang region, the vegetative growth period in the large field was correspondingly shortened. Demands were made to make up for any deficiency during the seed bed period. Thus the seedling age must be appropriately extended during the seed bed stage. This is beneficial to early maturity and creating high yields.

B. Tillering Stage

The tillering stage is the key period that determines the number of panicles and also the period in which the foundation for the number of grains per panicle is laid. The number of panicles is mainly determined by the basic number of seedlings being transplanted and the percentage of formation of panicles from tillers. In general, the number of panicles can be determined during the peak tillering period, or 7 to 10 days after the peak tillering period at the latest. External factors have the greatest affect upon the number of panicles about the time of the peak tillering period. Application of fertilizers at the beginning period of tillering will have a more visible effect upon increasing the percentage of formation of panicles from tillers. After the peak tillering period, application of fertilizers will produce no significant results. Application of fertilizers 10 days after the peak tillering period has passed will produce almost no visible effect upon increasing the number of panicles. Therefore, the requirement during the tillering period is to stimulate early tillering, prevent late tillering and, upon the basis of actively stimulating early tillering, control the occurrence of ineffective tillers and coordinate the growth relationship between the colony and the individual plant, thus achieving a full number of panicles and strong growth of the plant.

C. Panicle Growth Stage

The panicle growth stage is the key period that determines the number of grains per panicle and also the period for cultivating a strong stem and laying the foundation for the formation of the weight of grains. The number of grains per panicle is first determined by the number of spikelets per panicle. To have grains, there must be flowers. The second is the increase of the fruiting percentage and the reduction of the percentage of empty or semi-filled grains, because not all of the spikelets on each panicle will be fertilized and bear fruit and not all grains on those spikelets that are fertilized and bear fruit will be fully filled. Thus, to increase the number of grains on each panicle, both the number of spikelets on each panicle and the percentage of fruiting must be increased.

The number of spikelets on each panicle is determined by the conditions of growth during the 25 days between the time when the first bract (about 30 days prior to heading) tillers and the latter period of reduction of the pollen mother cell (about 5 days prior to heading). The first 5 days of that 25-day period (from the time the first bract differentiates to the beginning period of spikelet differentiation) are the reproductive stage of the spikelets. The young panicle differentiate and develop into primary and secondary branch stems and spikelets. The last 20 days of the 25-day period (from the beginning of the period of spikelet differentiation to the ending of meiosis) are the period of spikelet reduction and degeneration (when the branch stems and the spikelets degenerate, causing a reduction in the number of spikelets).

The percentage of fruiting is determined by the conditions of growth during the 70 days between the beginning of differentiation of the young panicles and the yellow ripe stage (30 to 40 days after heading).

D. Fruiting Stage

The fruiting stage is an important period in which the weight of grains is determined and the last stage of growth that affects the amount of yield. The weight of grain refers to the weight of the grains, usually expressed as the weight of 1000 grains taken at random and termed the 1000-grain weight. Two factors determine the weight of grains. One is the possibility of forming larger hulls during the development of the spikelet about the time of meiosis of the pollen mother cell to hold more filling substances (mainly starch). The other is sufficiency or insufficiency of photosynthetic products during the vigorous filling period after heading.

The grain hull is developed from the inner and outer glumes. The size of the glume is determined before heading and in particular during the period of meissis. Therefore if the nutritional condition during this period is good and the spikelet has a sufficient supply of carbohydrates, then the hull will be large and will be able to hold more filling substances and the 1000-grain weight will be heavy. Conversely, if the nutritional condition is poor during the development of the empty glume and the amount of carbohydrates is insufficient, then the empty glume will not be able to fully extend and the hull will be small and unable to hold much filling substances and the 1000-grain weight will naturally be less heavy. Thus, the prerequisite for determining the weight of the grain is the largeness of the volume of the hull so that development of the endosperm is not limited by the volume of the hull and that the endosperm can expand fully during the filling period. However, the size of the hull provides only a possible condition for raising the weight of the grain. It does not represent the weight of the grain. The true weight of the grain depends upon the degree of filling after heading. If the glume develops well but the leaves wither early during filling or the amount of photosynthetic products is insufficient due to other causes, then the rice will be small even though the hull is large and more unfilled grains will be produced. Thus, to increase the weight of the grains, every link in the growth

process must be grasped to create favorable conditions for increases in the weight of grains (increasing the size of the hull) and to maintain favorable conditions after heading so that the grains will fill fully and possibilities are changed into realities. In production practices, the major factor affecting the weight of grains is often the result of filling substances after heading (early weakening) or abnormal distribution and transportation of nutrients (remaining green and late maturation).

Therefore, the major problems must be grasped and solved so that the weight of grains can be increased.

Major References

1. Tokari Gishi [2073 0435 5030 2945] et al "Paddy Rice Physiology," translated by An Kegui [1344 0344 6311], Shanghai Science and Technology Press, 1959

2. Shanghai Teacher's University Biology Department (1974): "Physiology of Paddy Rice Cultivation" (Mimeographed)

3. Crop Cultivation Teaching and Research Group of the Zhejiang Agricultural College (1975): "Paddy Rice Cultivation."

Table 3. Diagram of the Growth of Double Crop Rice in the Shanghai Area and Weather and Fertilizer and Irrigation Control

月 (1) 份		4			5			6			7			8			9			10			11		
旬 (2)		上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)	上(4)	中(5)	下(6)
廿四节气 (3)		(7)	(8)		(9)	(10)		(11)		(12)	(13)		(14)	(15)		(16)	(17)		(18)	(19)		(20)	(21)		(22)
(23) 生育期	(24) 早稻	(25)			(26)		(27) (28) (29)	(30)					(31)												
		(32)			(33)		(34)		(35)																
	(36) 后季稻									(37)				(38)	(39)	(40)	(41)		(42)			(43)			
											(44)			(45)			(46)		(47)						
(48) 气候特点		(49)			(50)			(51)			(52)			(53)			(54)			(55)					
(56) 各旬天气	平均温度 (℃) (57)	13.0	14.1	15.8	17.3	18.6	20.5	21.9	23.1	24.8	27.1	28.0	28.5	28.8	28.1	27.1	25.6	23.4	21.8	19.8	18.3	16.0	14.9	12.7	9.7
	雨量 (毫米) (58)	34.3	33.7	37.0	48.7	30.4	35.0	47.1	46.9	70.0	61.0	34.6	30.2	39.6	23.0	48.3	58.1	65.6	35.7	24.3	18.3	13.3	16.2	18.9	14.8
	日照 (小时) (59)	46.0	53.3	54.5	47.3	49.5	63.8	63.5	57.0	50.5	63.6	78.3	100.9	88.6	87.3	53.5	62.0	60.5	57.1	61.5	63.2	62.9	60.4	45.2	52.6
(60) 施肥	氮 (61)	(64)			35.6			48.6		18.0				27.3			58.7			20.5			(65)		
	磷 (62)				18.7			57		24.5				15.9			47.4			61.8					
	钾 (63)				21.9			61.9		18.9				20.5			38.7			27.7					
(66) 施肥		(67)	(68)		(69)			(70)			(71)		(72)				(73)								
(74) 水浆管理 (最大持水量%)		(75) (70~80%)	(76)				(77)	(78)		(79)			(80)												
								(81)		(82)						(83)		(84)		(85)			(86)		

* 据上海市气象局 1961~1970 年平均资料。(87)

[Key to table on preceding page]

(1) month
(2) ten day periods
(3) 24 solar terms
(4) first ten days of the month
(5) middle ten days of the month
(6) last ten days of the month
(7) April 5
(8) April 20
(9) May 5
(10) May 21
(11) June 6
(12) June 21
(13) July 7
(14) July 23
(15) August 7
(16) August 23
(17) September 8
(18) September 23
(19) October 8
(20) October 23
(21) November 7
(22) November 22
(23) growth period
(24) early rice
(25) sowing
(26) transplanting and greening
(27) tillering
(28) jointing
(29) spike bearing
(30) heading and flowering
(31) harvest
(32) seedling stage
(33) tillering stage
(34) young spike differentiation
(35) flowering and maturity
(36) late season rice
(37) sowing
(38) transplanting and green
(39) tillering
(40) jointing
(41) spike bearing
(42) heading and flowering
(43) harvest
(44) seedling stage
(45) tillering stage
(46) young spike differentiation
(47) flowering and maturity
(48) weather characteristics,
(49) alternately cold and warm with incresing spring rain and frequent low temperature and late frost.
(50) warm weather with plenty of spring rain, frequent thunderstorms and rain and continuous cloudy and rainy day
(51) gradually becoming hot with frequent changes in sunny and rainy days.
(52) early summer rains, humid and hot, damp, plenty of rain and concentrated, plenty of thunderstorms and rains
(53) extremely hot weather, except for typhoons and partial thunderstorms and rain, the weather is hot and there is not much rain, and the summer season is dry.
(54) weather turns from hot to cool, before September 8 the weather is a "autumn tiger" weather, after September 8 autumn winds come and autumn rain falls. After September 23 cold air moves southward
(55) rain becomes scarce, the autumn air is cool, the weather becomes colder and early frost occurs during the latter period.
(56) weather during each ten day period
(57) average temperature °C
(58) amount of rain (centimeter)
(59) daylight (hour)
(60) amount of fertilizer needed %
(61) nitrogen
(62) phosphorus
(63) potassium
(64) early rice
(65) late season rice
(66) application of fertilizers
(67) base manure, weaning fertilizer
(68) surface base manure, rise-up fertilizer
(69) tillering fertilizer
(70) spike fertilizer
(71) rise-up fertilizer, surface base manure
(72) tillering fertilizer
(73) spike tertilizer
(74) water and muddiness control (greatest water retention %)
(75) dampness (70-80%)

(76) shallow wate and frequent irrigation
(77) drying the field
(78) shallow water and frequent irrigation
(79) day, day, wet, wet
(80) early rice
(81) damp
(82) shallow water and frequent irrigation
(83) drying the field
(84) shallow water and frequent irrigation
(85) day, day, wet, we
(86) late season ric
(87) Data taken from Weather Breau of Shanghai City for the years 1951-1975. Figures are averages.

CHAPTER 2. GERMINATION OF THE SEED AND GROWTH OF THE SEEDLING

Cultivation of a strong and healthy seedlings is the first battle in paddy rice production. Whether strong and healthy seedlings can be cultivated will greatly affect production. The poor and lower-middle peasants express it well: "Good seedlings mean the rice is [already] half-ripened" and "strong seedlings mean high yields." These sayings explain the importance of cultivating strong seedlings to increase production. It is generally believed new roots of strong seedlings emerge early and plentifully, absorb fertilizers strongly and use fertilizers more frugally than weak seedlings. With thick and strong seedlings, fewer need to be transplanted and seeds are conserved. Strong seedlings green up rapidly, tiller early, grow steadily, have thick stalks, have less diseases, do not easily lodge and produce plenty of panicles, plenty of grains, full grains and high yields. In the middle and lower reaches of the Chang Jiang region especially since the implementation of the double cropped rice and the triple cropping system, the growth period in seed beds constitutes about a third of the entire growth period. In terms of the period of vegetative growth, one half to two thirds of the entire vegetative growth period is spent in the seed beds. Therefore, in the cultivation of strong seedlings, a good foundation laid during the seedbed stage is an important link in realizing high yields.

To cultivate strong seedlings, the germination of seeds, and the growth process of seedlings and their demands upon external conditions must first be understood. With this understanding, effective measure can be better taken and man's subjective action can transform seedlings into healthy and strong ones.

I. Shape and Structure of the Seed

In production the ripe grain is generally called a seed. Actually it is not a seed but a fruit with a single seed (some have two seeds) have a glume (The palea and lemma do not belong to the fruit. Fruit refers to the rice grain only). During the development of the fruit, the pericarp and the seed coat do not separate easily but stay closely together. This type of fruit is called a caryopsis in botany. The grain consists of the glume and the rice kernel.

A. The Empty Glume

The glume is composed of two boat shaped lemma and palea hooked together. The glume on the outside is called the lemma (also called outer husk) and the glume on the inside is called the palea (also called inner husk). The tips of the glumes are the apicules. Some lemma have awns on the top. The length of the awns vary according to different varieties, the longest may reach over 6 to 7 centimeters. The sterile lemma grows at the base of the grain and is smaller, about one-third the length of the palea and lemma. Between the sterile lemma is the rachilla which is connected to the pedical at the bottom where there are rudimentary glumes. (Diagram 4)

1--sterile lemma
2--sterile lemma
3--lemma
4--palea
5--pubescence
6--pedical
7--rudimentary

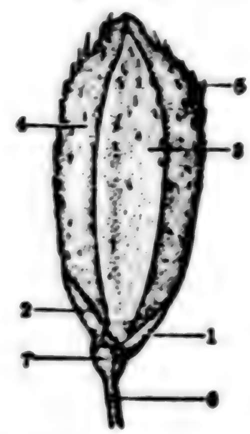


Diagram 4. Outer Shape of the Grain

B. The Kernel

The kernel is the husked grain (coarse rice). The surface of the rice is shiny, white or semi-transparent. Some rice are red, purple or black. Immature kernels appear green. The green color disappears when the kernel ripens and becomes white. The kernel consists of the skin (also called the pericarp), the endosperm and the embryo.

1. Epithelium

The epithelium consists of several pericarp layers and seed coat surrounding the outermost layer of the grain seed. The pericarp originates from aging, drying and shrinking of the ovary wall. It is green at the beginning but changes into a glassy color after ripening. The seed coat is in the inner side of the pericarp. It originated from the inner layer of the inner covering of the ovules and the remnant cells of the ovule core.

2. The Endosperm

Inside the pericarp is the endosperm. It occupies most of the kernel and its weight constitutes 85% of the weight of the seed. The endosperm contains large amounts of nutrients, mostly starch and lesser amounts of protein,

fat and small amounts of fiber and minerals. These nutrients serve as raw material for the building of the young sprout. Therefore, if the seeds are large and full, nutrients will be sufficient. This is the basis for cultivating strong seedlings. Large and full seeds selected for sowing will grow into young sprouts that have large leaves and plenty of roots.

The endosperm has an aleurone layer and starchy cells. The aleurone layer is connected to the seed coat. The cells are small but contain protein and fat. The side facing the embryo has a single aleurone layer. A few types of seeds have two aleurone layers on this side. The opposite side is think and has 5 to 6 aleurone layers. On the inner side of the aleurone layer is the starchy layer. These cells are large and contain starch. The starchy cells on the inside generally grow earlier than those closer to the outside. The growth pattern for this type of starchy cell is radial, extending from the center towards the perimeter in concentric circles. (Diagram 5)

The endosperm usually is semi-transparent. The part of the grain in the center that is white and not transparent is called the white mealy part. The center which is also white and not transparent is called the chalky white part. Parts of the tissues of the mealy white and chalky white parts are loose and brittle. They easily break apart during milling, reducing the number of grains. The size of the mealy white part is an important indicator of the quality of the rice. The existence and the size of the mealy white part in the grain vary with different varieties and climatic conditions. In general, the mealy white part of geng rice is smaller than that of xian rice.

Diagram 5. Starchy Cells of Paddy Rice

3. The Embryo

The embryo is located at the base of the rice kernel. It is the body formed by the fertilized ovum (Diagram 6) and is an important part of the seed. If the embryo in a seed is damaged by insects or other causes or has lost its vitality during the period of storage of the seed, then the seed will be completely useless for sowing. Thus, prior to sowing, the percentage of germination and the trend of germination of the seed must first be tested to determine the proper amount of seeds to be sown and to provide a good foundation for the emergence of full seedlings. Sowing seeds with a low percentage of germination in the fields is a waste of food grains, will cause many missing seedlings and affect completion of planting plans.

The weight of the embryo constitutes about 2% of the weight of the seed but the embryo contains large amounts of highly energetic nutrients such as protein, fat, sugars, phosphorus esters, vitamins, enzymes and plant hormones which are physiologically necessary and highly active physiological substances.

The embryo is composed of the plumule, embryo axis, radicle and the cotyledon (Diagram 6). The plumule includes the apical point of the stem, the plumule sheath and the two surrounding young leaves and a leaf primordium. When the seed germinates, the plumule grows into the part of the paddy rice plant above ground--the stalk and leaves. The first to emerge from the plumule is a sheath—like protrusion called the plumule sheath. The radicle is located at the bottom part of the embryo and is surrounded by the radicle sheath. When the seed germinates, the radicle breaks through the seed coat and extends outward as the root of the seed. The embryo axis is the part connecting the plumule, the radicle and the cotyledon. The cotyledon grows on one side of the embryo axis between the embryo and the endosperm in the shape of a shield, thus it is also called the shield blade. The outer cells on the side of the cotyledon next to the endosperm are called epithelium cells. When the seed germinates, the epithelium cells produce hydrolytic enzymes to decompose the nutrients in the endosperm and absorb and transport the nutrients to the growing parts for use.

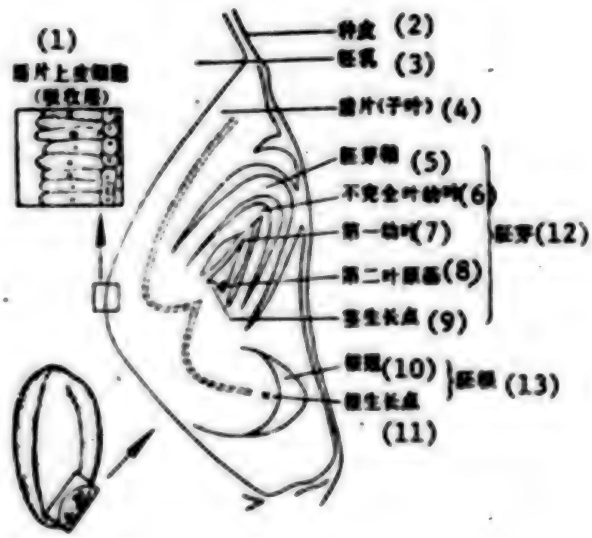


Diagram 6. Structure of the Seed of Paddy Rice (Hoshigawa Kiyoshin, 1971)

Key:
- (1) upper epidermal cells of the cotyledon
- (2) pericarp
- (3) endosperm
- (4) cotyledon (seed leaf)
- (5) plumule sheath
- (6) young leaf of incomplete leaf
- (7) first young leaf
- (8) second leaf primordium
- (9) meristem of stem
- (10) root cap
- (11) meristem of root
- (12) plumule
- (13) radicle

II. Germination of the Seed

A. Germination Process of the Seed

The process of germination involves termination of the dormancy of the seed and transformation from an inactive stage to a visibly active stage and initiation of growth under proper temperatures, sufficient moisture and sufficient supply of oxygen. The process of germination of the paddy rice seed can be divided into three stages of absorption and expansion, germination, and budding.

1. Absorption and Expansion Stage

Absorption of moisture and expansion are the first step in the germination process. The seed contains large amounts of hydrophilous colloids of protein and starch. Thus, seeds that have been dried by wind have a very strong ability to absorb water. When the seeds are soaked in water, they quickly absorb the water and expand. After the seeds have absorbed sufficient water, their physiological activities such as activation and production of enzymes, strengthening of respiration and the transformation and transportation of material..., gradually begin and normal germination of the paddy rice seed becomes possible.

2. Germination Stage

As the absorption and expansion of the seed and the moisture content of the seed increase, the metabolism within the seed becomes active. At this time, two opposing and united processes inside the seed occur: One is the decomposition of the nutrients stored in the endosperm into simpler and soluble substances. The other is the absorption of the products of decomposition by the embryo and their resynthesis into new and complex organic substances forming new cells and increasing the number and expanding of the size of the cells. When the size of the embryo enlarges to a certain point, the embryo breaks through the seed coat and emerges. This is called "showing white." Under normal conditions, the plumule sheath first breaks through the seed coat and then the radicle follows.

3. Budding Stage

After the seed begins to germinate, the embryo continues growing. In general, budding is indicated when the length of the plumule (young bud) measures half that of the seed and the length of the young root equals the length of the seed.

B. Material Transformation During Germination

Germination of the paddy rice seed takes place under definite external conditions (such as moisture, temperature, oxygen). Active cells, with the help of the catalytic function of enzymes, decompose the starch stored inside the endosperm into substances of smaller molecular structure such as glucose

and the stored protein into amino acids which are transported through the epithelium of the cotyledon to the embryo to provide for respiration and growth of the cells of the embryo.

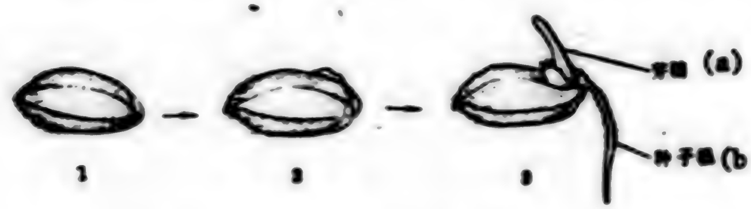


Diagram 7. Process of Germination of the Paddy Rice Seed
1. Absorption and expansion; 2. showing white (germination), 3. budding

Key: (a) plumule sheath
(b) root of the seed

1. Transformation of Starch

The seed of paddy rice contains about 72% starch. It is stored in the cells of the endosperm as compound starch granules (some are singular granules). The compound starch granules are round in shape, about 3 to 10 millimicrons. When the seed is dry, the compound starch granules are complete. After absorption of water, the outer membrane of the compound starch granules dissolves and breaks open under enzymic activity. Single starch granules of polygonal shape are released. As germination proceeds, the surface of the single starch granules appears to have been eaten away because of the function of the amylolytic enzyme. These erosions gradually deepen until the single starch granule is shattered and finally dissolved (Diagram 8).

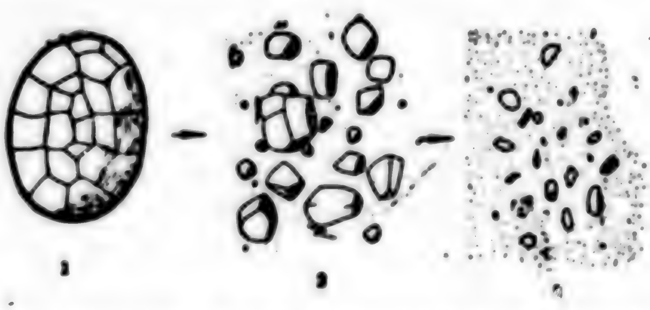


Diagram 8. Digestive Process of the Compound Starch Granules of Paddy Rice (Hoshigawa Kiyoshin 1975)
1. before absorbing water; 2. after absorbing water (single starch granule)
3. single granule is broken into loose pieces.

If we analyze the above transformation process biochemically and systematically analyze the carbohydrates and their hydrolytic enzymes in the grains, we will see that the activity is the result of the function of the R-enzyme,

β-amylic enzyme, α-amylic enzyme and phosphatase which change the starch in the grain gradually into sugar (Diagram 9).

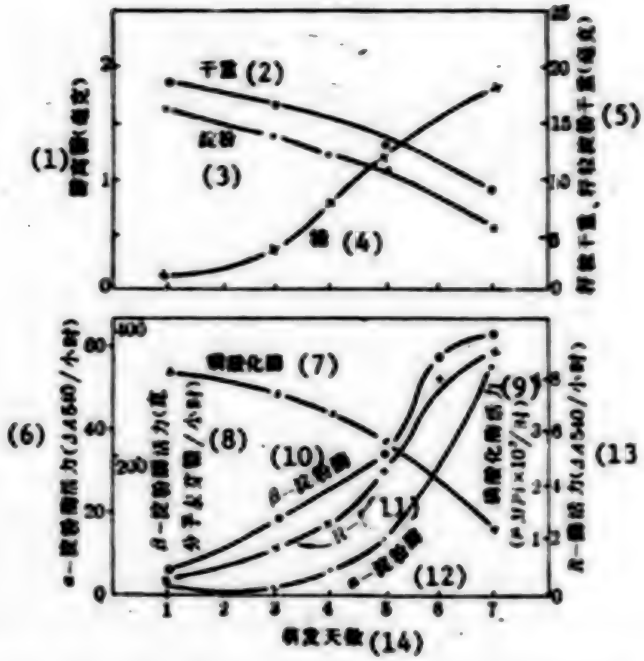
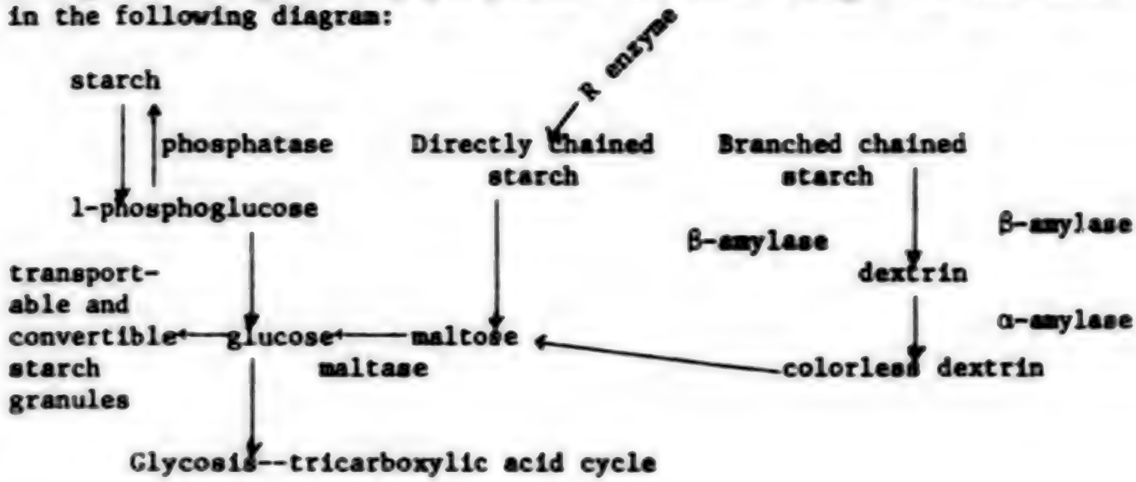


Diagram 9. Changes in carbohydrates and their hydrolytic enzyme activity during germination of the paddy rice seed (variety: IR-8) (Palmiano, E.P., 1972)

Key:
(1) Ionic sugar (milligram)
(2) dry weight
(3) starch
(4) sugar
(5) dry weight of seed grain, dry weight of starch in seed grain (milligram)
(6) α-amulolytic enzyme activity (ΔA540/hour)
(7) phosphatase
(8) β-amylolytic enzyme activity (gram molecular maltose/hour)
(9) Phosphatase activity (μMPix10/hour)
(10) β-amylolytic enzyme
(11) R-enzyme
(12) α-amylolytic enzyme
(13) R-enzyme activity (ΔA540/hour)
(14) Day of germination

Starch can be divided into directly chained starch and branched chained starch. Ordinary nuo [glutinous] rice contains over 80% of branched chained starch while xian rice contains mostly directly chained starch. Geng rice is in between. Branched chained starch is not soluble in hot water but can be decomposed by R-enzymes (starch-1, 6-glycosidase) into directly chained starch or hydrolyzed by the β-amylic enzyme into dextrin. Dextrin can be

further hydrolyzed by the α-amylic enzyme into colorless dextrin and maltose. Directly chained starch is soluble in hot water. It turns blue when mixed with iodine. It can be hydrolized by the β-amylic enzyme into maltose. Maltose is in turn hydrolized by maltase into glucose. Starch can also be decomposed into glucose by phosphates. The above changes are illustrated in the following diagram:



After the product of hydrolysis of starch i.e., glucose, is transformed into saccharose, it enters the seed embryo and is synthesized into glucose again. Glucose is a very active intermediate product which can participate in various kinds of biochemical reactions. It serves first as the major basic matter in respiration. Via respiration, glucose enters various metabolic channels to provide energy for germination of the seed and growth of the radicle and the plumule and serve as the material basis for building of the organs. Glucose that is not immediately used by the embryo is resynthesized in the cotyledon cells as "rotating starch" and temporarily stored for use when needed.

2. Transformation of Protein

Protein in the paddy rice seed is mainly stored in the aleurone layer of the endosperm, existing mostly in a formless state. Sometimes protein crystals can be seen. Generally, protein constitutes about 8% of the weight of the seed. When the seed germinates, the stored protein is hydrolyzed into various amino acids by the action of proteinase (which hydrolyzes protein into polypeptides) and peptidase (which hydrolyzes polypeptides into amino acids) (Diagram 10).

The amino acids resulting from hydrolysis are mostly remade into structural proteins which become part of the cells of the young leaves and young roots. Thus, when the seed germinates, the amount of stored proteins reduces while the amount of structural proteins increases. Sometimes a part of the amino acids is deaminized to yield "ammonia." This ammonia then reacts with the aspartic acid to form asparagine, temporarily placing the ammonia in storage for future decomposition and use when needed. The nitrogen from the amide

and the nitrogen from the fertilizers applied externally can also unite with the keto acids (α-ketoglutaric acid, oxaloacetic acid, pyruvic acid) or unsaturated acids (fumanic acid) produced by oxygenic respiration to form new amino acids and structural protein for growth of new organs of the young roots and young buds. The following diagram illustrates the transformation process of protein during the germination of the seed and growth of the young sprout.

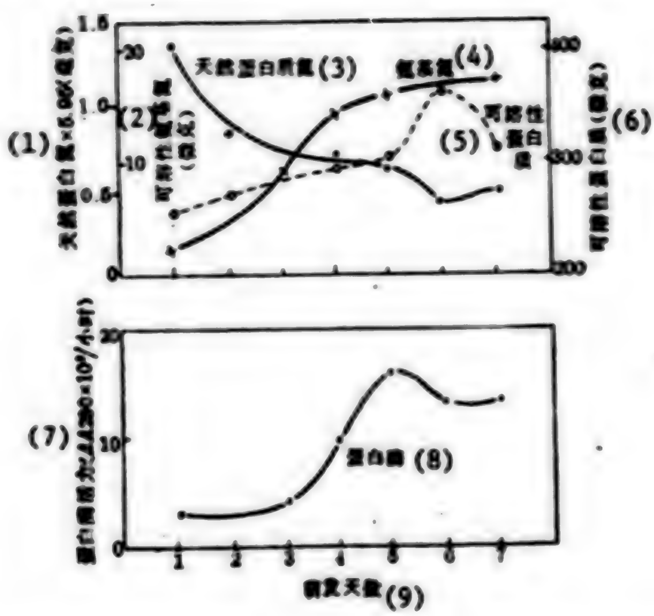


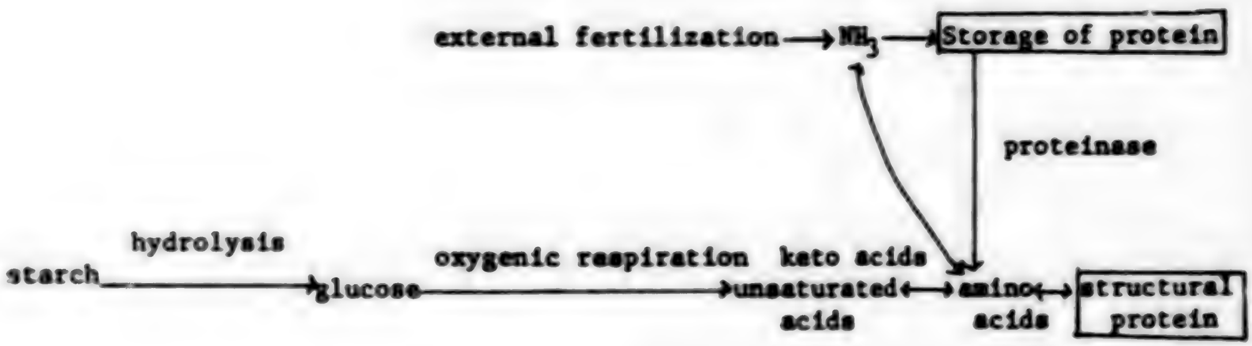
Diagram 10. Changes in activity of proteinase and nitrogenous compounds during the period of germination of the seed of the IR-8 variety Paddy Rice (Palmina, E. P., 1972)

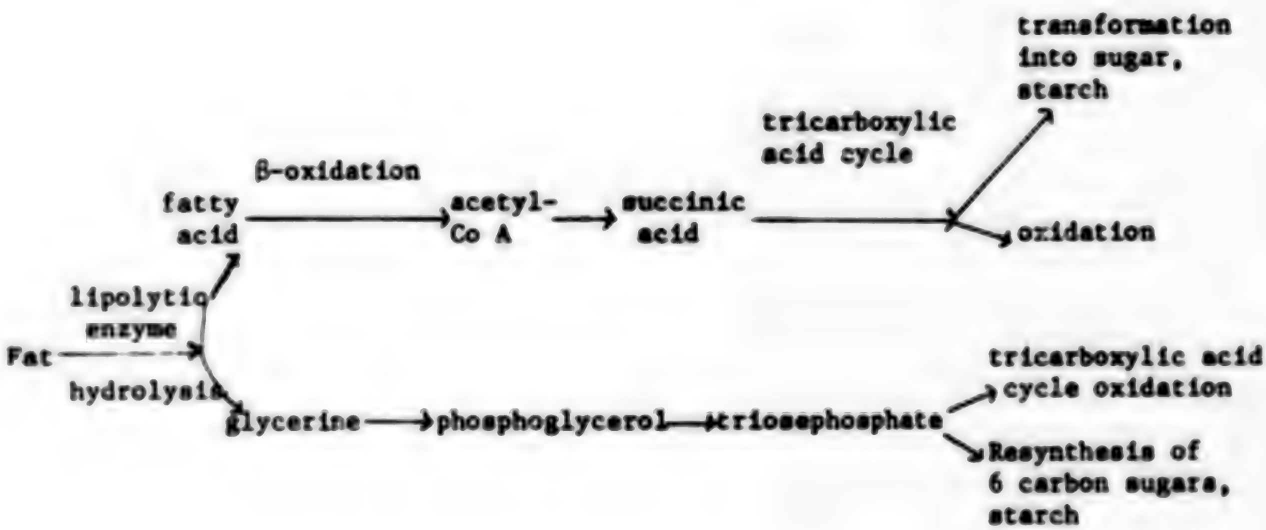
Key: (1) natural nitrogenous protein x 5.95 (milligram)
(2) soluble amino nitrogen
(3) natural nitrogenous protein
(4) amino nitrogen
(5) soluble protein
(6) soluble protein (milligram)
(7) Proteinase activity (A280 x 10^2/hour)
(8) proteinase
(9) number of days of germination

3. Transformation of Fat

The seed of paddy rice contains very small amounts of fat, constituting only 1% to 2% of the weight of the seed. Fat exists as small oily drops scattered in the cytoplasm and contains little oxygen within it. During oxidation, it can release more energy for use during germination. When the seed germinates, the fat, by the action of lipolytic enzymes, decomposes into

fatty acid and glycerine. Fatty acids decompose into acetyl-Co A mainly by β-oxidation and transform into sugar via the acetic aldehyde cycle. Glycerine decomposes directly into triose and is utilized in respiration or transformed into sugar. These are illustrated in the following diagram:





C. Conditions for Germination of the Seed

Germination of the paddy rice seed requires two basic conditions, the ability of the seed to germinate and definite external environmental conditions.

1. Ability of the Seed to Germinate

The germinating ability of the seed is closely related to the degree of maturity and the conditions of storage. It is generally believed that during the one week after flowering and pollination of paddy rice the seed acquires the ability to germinate. After 2 to 3 weeks, the seed's germinating ability is strengthened. However, seeds at this stage are still not completely mature and they germinate very slowly, their chances of rotting are high and their percentage of germinating is low. As the seeds mature, their germinating ability continues to increase until they reach the waxy ripe stage when their ability to germinate reaches a high level.

The seeds of some varieties do not have a high percentage of germination after they reach maturity even when planted under suitable external conditions. They need to be stored for a definite period for further ripening before they can germinate normally. This characteristic is called the dormancy of seeds. In general, xian rice seeds have a short period of dormancy; especially xian varieties of early rice almost do not require any dormancy period. Thus these varieties should be harvested timely. If the harvesting time is missed and if it rains during the period of maturation, the seeds may easily germinate while still on the panicle, affecting yield and quality. Geng varieties have a definite period of dormancy, especially the late geng varieties. Because permeability of the seed coat is closely related to the dormancy period of the seed, seeds for production, therefore, are often dried under the sun to increase the seed coat's permeability. As the seeds are being dried, the cells of the seed coat separate from each other, thus increasing the permeability of moisture and oxygen through the seed coat, reducing the moisture content inside the seed and allowing the substances inside the seed such as carbon dioxide which hinder germination to be released. This eliminates the dormancy requirement of the seeds and greatly increases the percentage of germination and the assurance that germination of strong buds is stimulated.

Seeds not yet completely ripe and less [illegible]led often cannot complete the process of further ripening before sowing. This in turn affects timely germination and results in a low percentage of germination. Therefore, seeds must be selected prior to sowing so that [only] fully ripened and fully filled grains are used.

Conditions of storage also affect the strength of germination greatly. When the moisture content of the seeds is below 14%, seeds stored under cool, dry conditions, which require weak respiration and little consumption of dry substances within the body of the seeds, can retain germinating ability for 3 to 6 years. As the number of years of storage increases, the germinating ability of the seeds visibly reduces. However, under normal storage conditions the germinating ability of seeds can be retained for 2 to 3 years. Therefore, in production it is better to select fresh seeds one year old.

2. Conditions for Germination of Seeds

Seeds that have passed their period of dormancy and possess the ability to germinate can germinate when conditions for moisture, temperature and oxygen are satisfied.

(1) Moisture: When the paddy rice seed contains 14% to 12% moisture or less, the moisture within the seed exists in the form of bonded water. The protoplasm exists in a gel state. Enzymes exist in a retarded state. The only activity is weak respiration. Therefore, the paddy rice seed can remain in storage for a long period without germinating.

Before the seed germinates, it must first absorb sufficient moisture. When the seed has absorbed an amount of water equal to 25% of its own weight, it will begin to germinate but slowly and not uniformly. When the amount of water absorbed is equal to 40% of its own weight, it will have reached saturation. (The external characteristic at this time is that the grain husk appears semitransparent and the mealy white and the embryo can be clearly seen.) This is the most suitable moment for germination. The purpose of soaking the seeds is to create the condition for the seeds to absorb sufficient water for germination and allow the seeds to absorb water equally so that the protoplasm of the cells can change from a gel state to a dissolved colloidal state. The increase in free water inside the seed provides proper conditions for activation of enzymes and material transformation. In addition, after the seeds have absorbed water, the seed coat softens, permeability increases, oxygen can easily enter the seed, respiration intensifies, stored substances inside the endosperm are quickly decomposed and transported to the embryo, cells of the embryo continue to split, elongate, absorb water and expand and finally break through the seed coat and the young root and the young bud gradually extend.

Absorption of water by the paddy rice seeds can be divided into three stages (Diagram 11): The first stage (A) is the physical process of absorption and expansion due to massive intake of water. In this stage, almost half the amount of water needed for germination (showing white) is absorbed. The second stage (B) is the biochemical process of slow absorption of water. A certain time is needed for enzymes to become active for material transformation and transportation within the seed. The third stage (C) is the process of massive absorption of water for growth of new organs. Thus, in the process of soaking the seeds and forcing the seeds to germinate, it is important to assure sufficiency of water for the first and the third stages.

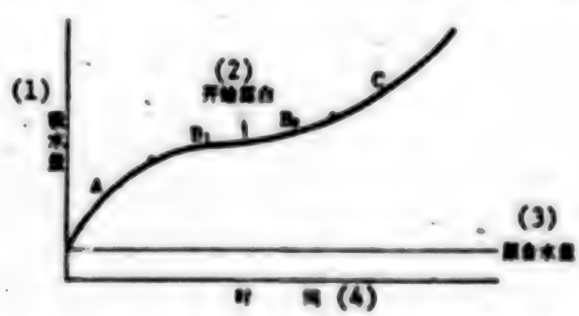


Diagram 11. Model Diagram of Absorption of Water by the Paddy Rice Seed (Lu Dingzhi 1965)

Key: (1) amount of water absorbed (4) time
(2) beginning to show white
(3) original water content

The speed with which the paddy rice seed absorbs moisture is related to the thickness, moisture permeability and water content within the seed of each variety. It is most closely related to temperature. The seed absorbs water fas er at higher temperatures and slower at lower temperatures. It has been determined that at a water temperture of 10°C, the seed needs over 90 hours to absorb enough moisture. At a water temperature of 30°C, only 40 hours are needed. Thus, in soaking seeds during early spring when the temperatures are low, insufficient moisture absorption should be avoided by soaking the seeds at least for three days. For sowing late season rice, generally two days of soaking is required since the temperatures during that period are higher and over soaking of the seed should be avoided. If the seed is soaked for too long, the nutrients in the endosperm will leak out, causing the seed to become sticky (commonly referred to as "syrupy sugar"). This greatly affects forced germination and may cause the seed to die if the seed is seriously affected by the "syrupy sugar" phenomenon. Less seriously affected seeds will not grow into strong sprouts when forced to germinate. The duration for soaking the seeds (designated by the product of the number of days and temperature) of xian rice to "allow sufficient absorption of moisture is 60 day-temperature, i.e., 4 days at a daily average temperature of 15°C or 3 days at a daily average temperature of 20°C (geng rice needs 80 day-temperature to absorb sufficient moisture). Paddy rice seeds that have absorbed sufficient moisture will grow uniformly, strongly and healthily when forced to bud. Conversely, if the amount of moisture absorbed is insufficient, neither forced budding nonsprouting will not be uniform after sowing.

(2) Temperature: After the paddy rice seed has absorbed sufficient moisture, there must also be a definite temperature before it can germinate. This is because the physiological and biochemical changes during the germination process of the seed take place under the stimulation of enzymes. The catalytic activity of enzymes is related to temperature. Enzymic activity increases as temperatures rise, the stored substances in the seed decompose faster and the speed of germination becomes faster. Therefore, seed germination requires a definite temperature. At the same time, the growth of the embryo also requires a definite temperature. Experiments show the lowest temperature under which the paddy rice seed can germinate is between 10°C and 12°C. The most suitable temperature for germination is around 35°C and the highest temperature for germination is about 40°C. If the seed has absorbed enough moisture, it will not be able to germinate with a temperature below 10°C, and after some time, disease-causing bacteria will enter the seed and cause the seed to rot. At a temperature of 20°C, the seed is able to germinate but the time required for budding is longer. This easily causes the buds to emerge unevenly. At a temperature of 35°C, the buds quickly and uniformly show white. This is most beneficial to proper germination. The young root and the young sprout grow fast and uniformly. But after showing white, if the temperature remains at 35°C, the roots and sprouts will grow too rapidly and become thin and weak. If soon after showing white the temperature gradually drops to 25°C, then the speed at which the roots and sprouts grow will slow down enabling the young sprouts to grow strong. The above constitutes the scientific basis of the requirements for forced budding practiced by the broad poor and lower-middle peasants who "allow the seeds to show white when it is hot and allow the buds to grow when it is damp." When the temperature is above 42°C, extension of

the young root and young sprout will be hindered. If such high temperatures persist, the protoplasm in the cells will mutate and the high temperatures may even parch the young root and young bud. Thus when forcing the seed to germinate, the temperature of the seed pile must quickly be raised to 35°C and held constant until prior to showing white. This will enable the seeds to rapidly and uniformly show white. After showing white, the "buds" are then nourished under a temperature of 25°C to prevent overly high temperatures from "parching the buds." In forced budding, when the bud grows the length of one grain, the root should correspondingly grow the length of half a grain. Seeds sown early should be allowed to bud for a longer period so that they can root early. Seeds sown late should bud for a shorter period. Late season rice seeds can be sown after showing white.

Seeds that have not absorbed moisture and have not begun to germinate are more tolerant to high temperatures. Germination will not be affected by soaking in 55°C warm water for less than 25 minutes or in 60°C warm water for less than 10 minutes. Therefore, in production warm water can be used to treat the seeds before soaking.

(3) Oxygen: All life forms require an energy supply for them to function. As the paddy rice seed germinates, we can see an increase in the seed's intake of oxygen (Diagram 12) due to active respiration. Respiration stimulates decomposition and transformation of substances stored in the seed which provide the material and energy bases for germination of the seed and growth of the young sprout. At the same time, transformation of starch and proteins in the endosperm is related to the intermediate metabolic substances of respiration, all of which can be transformed into each other. Therefore respiration is the center of material metabolism within the living body. The process of respiration is the gradual decomposition of parts of organic matter (the most important and most common substance consumed in the respiration process is glucose) and oxidation to form carbon dioxide and water and release of energy. It can be expressed in the following formula:

$$C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O + 674 \text{ large calorie}$$

But under conditions of insufficient oxygen, glucose undergoes a different transformation. Only anaerobic respiration is possible (alcoholic fermentation). Alcohol and carbon dioxide are produced. The amount of usable energy thus produced is small. If, in the process of soaking and forcing the seeds to bud, the seeds are not frequently stirred, a small amount of alcohol will merge from the seeds as a result of anaerobic respiration. The following formula illustrates the process of anaerobic respiration:

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{enzyme}} \underset{\text{(alcohol)}}{2C_2H_5OH} + 2CO_2 + 24 \text{ large calorie}$$

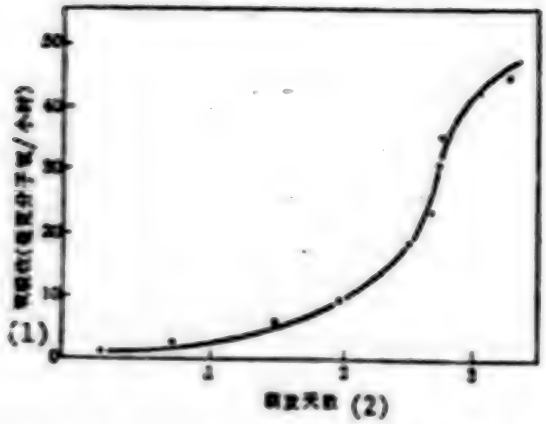


Diagram 12. Changes in oxygen intake during germination of the Paddy Rice Seed of Variety IR-8 (Palmiano, E.P., 1972)

Key: (1) Oxygen intake (milligram molecular oxygen/hour)
(2) Number of days of germination

Research shows that the respiration of the young paddy rice seedling takes place in several forms including glycosis and the tricarboxylic acid cycle and oxidation. Glycosis and the tricarboxylic acid cycle are illustrated below:

a. Glycosis:

The Emden Meyerhof Pathway (EMP) glycosis is the process oxidation of glucose to pyruvic acid.

As illustrated in Diagram 13, glucose is catalyzed by hexokinase to form glucose-6-phosphate. Glucose-6-phosphate is isomerized to fructose-6-phosphate which is phosphatized to fructose-1,6-diphosphate. Then aldolase acts to decompose fructose-1,6-diphosphate into phosphodihydroxyacetone and 3-phosphoglyceraldehyde. The latter is decarboxylated and phosphatized to 1,3-diphosphoglyceric acid. The action of the phosphoglyceric acid enzyme releases a molecule of high energy phosphate bond from 1,3 diphosphoglyceric acid. This yields 3-phosphoglyceric acid. The action of phosphoglyceromutase changes the high energy phosphate bond from C_3 to C_2 to become 2-phosphoglyceric acid. This in turn releases another high energy phosphate bond by enolization to become pyruvic acid.

It can be seen from the above reaction that oxygen is not involved in the Emden Meyerhof glucosis process, only decarboxylation of the molecules themselves accompanied by the production of energy and the final production of pyruvic acid. This is the common pathway of glycosis for oxygenic and anaerobic respiration. Under anaerobic conditions, the pyruvic acid produced by Emden Meyerhof glycosis can undergo alcoholic fermentation to produce alcohol and carbon dioxide.

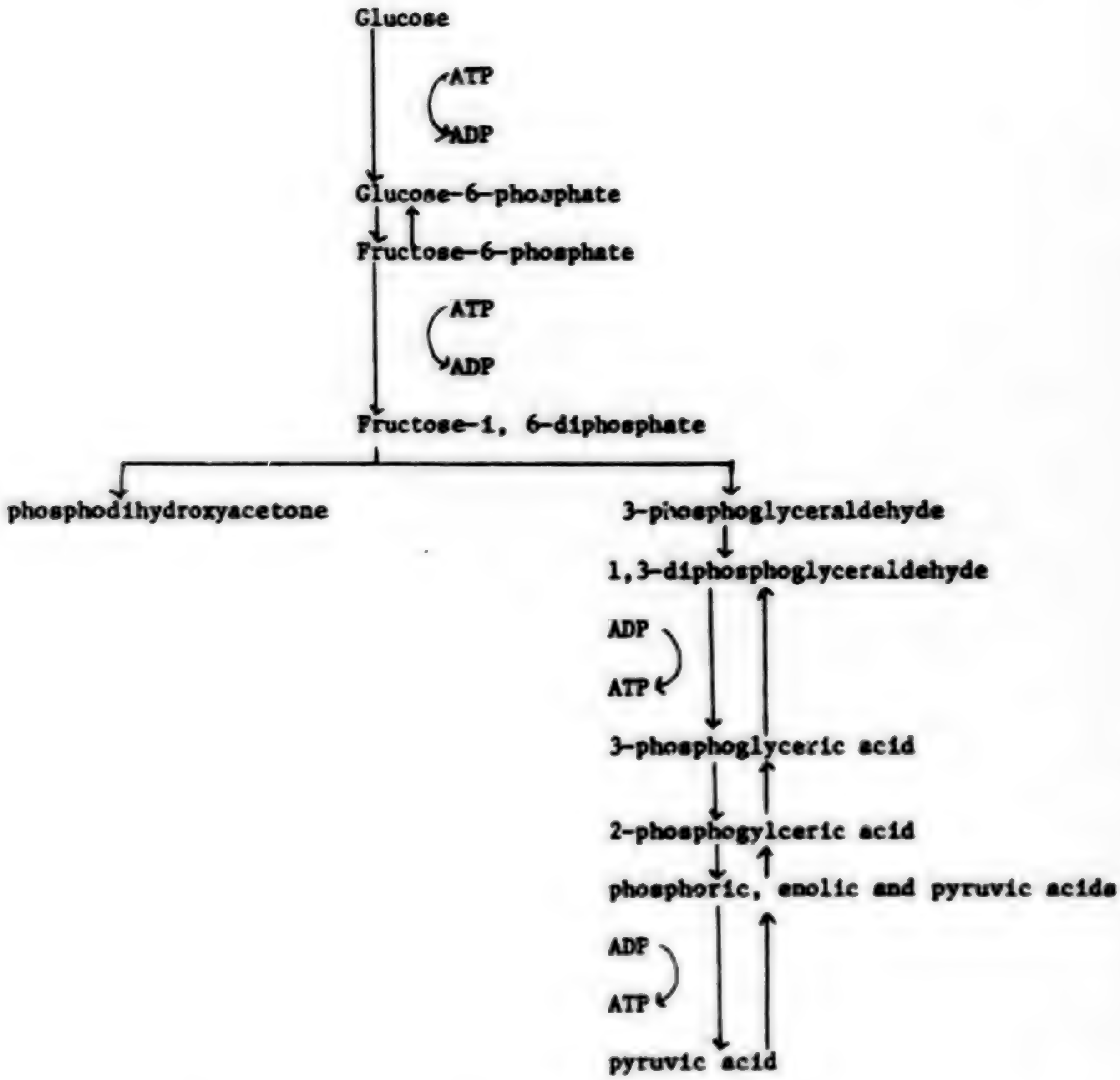


Diagram 13. EMP (Emden-Meyerhof Glycosis) Pathway

b. Tricarboxylic acid cycle: The pyruvic acid produced by the Emden Mayerhof glycosis can be completely oxidized to carbon dioxide and water under oxygenic conditions which release energy (ATP (adenosine triphosphate)). In biochemistry, this series of reactions is called tricarboxylic acid cycle (TCAC) and is illustrated in Diagram 14.

Our nation's scientists have shown that the three oxidation cycles take place in the young paddy rice seedling. Besides the tricarboxylic acid cycle, the gycollic aldehyde cycle (GAC) and the dicarboxylic acid cycle (DCAC) also take place. The ratio of occurrence of TCAC:GAC:DCAC is 10:2:1.

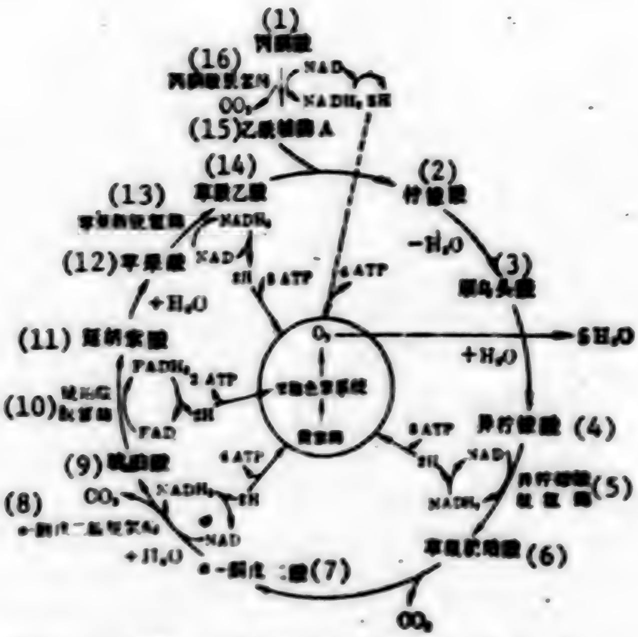


Diagram 14. Tricarboxylic Acid Cycle

Key:				
	(1)	pyruvic acid	(9)	succinic acid
	(2)	citric acid	(10)	succinic acid dehydrogenase
	(3)	cis-maleic acid	(11)	fumaric acid
	(4)	isocitric acid	(12)	Malic acid
	(5)	isocitric acid dehydrogenase	(13)	Malic acid dehydrogenase
	(6)	oxaloacetic succinic acid	(14)	oxaloacetic acid
	(7)	ketoglutaric acid	(15)	Acetyl-CO-A
	(8)	α-ketoglutaric dehydrogenase	(16)	pyruvic acid dehydrogenase

According to the characteristics of metabolism of the paddy rice seed during germination, germination of the paddy rice seed can be divided into two qualitatively different stages. The first stage is between the time the seeds undergo absorption and expansion and the time seeds burst open. The major concern during this stage is moisture. The major form of respiration during this period whether under oxygenic or anaerobic conditions is anaerobic respiration (alcoholic fermentation). It is characterized by highly active dehygrogenases. The plumule germinates but the young root has not yet extended. No oxygen enters the interior of the seed. The energy required for the growth of the plumule sheath is mainly supplied by fermentation. The coefficient of respiration is greater than 1. Oxidation-reduction is inactive. Growth of the plumule sheath depends upon the material content of the embryo. The second stage is the period after the seed bursts. The seed has already absorbed enough moisture by this time and without the limitations of the glume, oxygen freely enters the interior of the seed. The activity of many types of oxidase increases as the amount of oxygen intake increases. Respiration is mainly oxygenic (tricarboxylic acid cycle). The root of the seed and the

incomplete leaf grow rapidly and the amount of dry substances increases. Seeds that have already germinated and placed under anaerobic conditions will still carry on anaerobic respiration (such as alcoholic fermentation). Although life can still be sustained temporarily, long periods of anaerobic respiration are harmful to the germination of the paddy rice seed and growth of the young sprout because of the insufficient production of intermediate substances (such as pyruvic acid) due to anaerobic respiration which affects the supply of raw material for synthesis, because of the reduced amount of energy released by anaerobic respiration which constitutes only about 1/19 of the energy released by oxygenic respiration and because alcohol as a product of decomposition is poisonous to the cells. If during the process of forced budding the grain pile is too think, if there is too much moisture, if the temperature is too high and if the seeds are not frequently turned and stirred, the smell of alcohol will emerge from the pile and budding will be affected. After sowing, rotting of the buds which have been submerged in water for a long period is also related to anaerobic respiration over a long period.

Respiration provides the energy for metabolic activities involved in germination and also produces many chemically active intermediate substances as raw materials for further synthesis of new cells during the respiration process. Thus, it can be believed that respiration is not only the center of metabolic activity during the process of germination of the seed and growth of the young sprout, but also an important living activity throughout the entire growth process of paddy rice. Respiration is the source of energy for life activities and also provides the material basis for life activities.

During the process of forced budding, respiration of the grain is stronger than respiration while the grain is being soaked. When the seeds show white, respiration intensifies sharply to a hundredfold and then gradually weakens. The Zhejiang Agricultural College has measured the intensity of respiration of the rice grain. At the beginning of forced budding, each grain consumes 0.133 microliters of oxygen per hour. At showing white, each grain consumes 4.134 microliters per hour. The intensity of respiration at showing white is 31.09 times the intensity of respiration at the beginning of forced budding. This trend increases until the time when the buds have achieved uniform growth. The intensity then reduces and levels off. This indicates that the peak period of respiration is between showing white and the time when uniformed budding has been reached. A large amount of thermal energy is released during this period. This provides us with a basis for controlling the temperature of the rice grain, preventing the buds from being parched and for forcing the emergence of strong buds.

III. Growth of the seedling

A. Leafing

After the seed germinates, the plumule sheath is the first to emerge from the part of the seedling above ground. The plumule sheath does not have a midrib vein and does not contain chlorophyll making it colorless. Then the sheath (a leaf sheath without a body) called the incomplete leaf grows from

the plumule sheath. Since it contains chlorophyll, it appears green. This is called "showing green." Later, the first complete leaf (the first leaf) emerges from the leaf sheath of the sheath. The second emerges from the leaf sheath of the first leaf, the third leaf emerges from the leaf sheath of the second leaf..... (Diagram 15)

Diagram 15. The Paddy Rice Seedling

1. crown root
2. plumule sheath
3. incomplete leaf
4. first complete leaf
5. second complete leaf
6. third complete leaf

Under similar external conditions, the number of leaves emerging from the main stem of plants of a variety throughout the life of the plant is generally the same. For example, early rice variety "Ainanzao No 1" (early maturing) will have 12 leaves, "Guangluai No 4" (late maturing) will have 13 leaves. Late season rice varieties such as "Guihuahuang" will have 12 to 13 leaves, "Huxuan 19" will have 13 leaves, "Jianing 482" will have 14 leaves, "Jianong 15" will have 14 to 15 leaves, "Nongken 58" will have 15 leaves. When the transplanting time and external conditions change, the number of leaves emerging throughout the life of the plant changes slightly, generally within a difference of 1 or 2 leaves.

B. Leaf Age

The number of leaves on the main stem of the paddy rice plant throughout its life are symmetrically stable. Beginning from the seed bed cultivation period, the number of leaves on the main stem is counted to indicate the age of the plant. This is called the leaf age. A definite leaf age represents a definite stage of physiological growth of the plant body. Thus, leaf age can relatively accurately indicate the process of growth and development of paddy rice and the effect of external conditions upon the growth of the seedling. For example, young panicles of ordinary varieties begin to differentiate when

the reverse third leaf emerges. Another example is when the seedling is transplanted at a leaf age of 5.2, the 6th leaf sheath and the 7th leaf are extending. If the plant suffers from machinery damage during transplating (called plant damage), the leaves will grow especially short, even shorter than the previous leaf sheath and leaf. The marks of damage during transplanting thus remain.

The method determining the leaf age is as follows. The first complete leaf of the seedling to extend is marked "1" (and the entire period during which the first leaf grows is designated the first leaf period). The second complete leaf to extend is marked "2", and so on. If a certain leaf has not extended completely, then the length of the leaf already emerged as a percentage of the length of the entire leaf is taken in the calculation. For example, when the extended portion is 40% of the entire length of the leaf, the leaf age is designated as 0.4. When determining the proportional length of a leaf not yet fully extended, the entire length of the leaf is unknown. It is generally acceptable to estimate the length of the entire leaf by measuring the length of the previous leaf which has already extended fully and express the proportional length of the leaf as a percentage of the length of the entire length of the previous leaf. For example, when the third leaf is about 0.6 the length of the second leaf, then the leaf age of the seedling is 2.6 (or the third leaf period). Since the bottom leaves of the seedling wither and die as the upper leaves emerge, the leaf age should be marked every three to four leaves apart with red paint. However, during the seed bed period, the seedling age can be determined correctly without marking the leaves by uprooting the seedling along with the husks. This is because the odd numbered leaves (1,3,5 leaves) always grow on the same side as the rice grains while the even numbered leaves (2,4,6 leaves) always are on the opposite side of the grains. In addition, the extension of the first, second and third leaves is visibly affected by the supply of nutrients of the seed. Generally the lengths of the first, second and third leaves are 1 to 1.5 millimeter, 4 to 5 millimeters and 7 to 9 millimeters respectively. Thus, frequent attention will assure correct determination of the leaf age of every seedling even if the bottom first and second leaves have withered and died.

Different varieties having the same total number of leaves on the main stem generally reach the same stage of physiological development at the same leaf age. Varieties having different total numbers of leaves on the main stem do not reach the same stage of development even if their leaf ages are the same. Thus it is important to understand the relationship between the leaf age and growth development in making diagnostic observation of the seedling and determining the measures of cultivation for particular varieties.

C. Rooting

After the grain seed germinates, the first to extend is the seed root. After the first complete leaf has emerged, two roots designated 2 and 3 emerge from the plumule sheath node first and followed by two other roots designated 4 and 5 on the opposite side. A 6th root then grows from the top of the seed

root on the same side as the seed root. These five roots are called plumule sheath nodal roots and the masses c.ll them "chicken claws" (Diagram 16). When the second and third complete leaves emerge, five to six roots emerge from the nodes of the incomplete leaf. Then, at the 4th leaf period, roots emerge from the node of the first complete leaf. At the 5th period, roots emerge from the node of the second complete leaf,..... Thus, beginning from the 4th leaf period, a definite relationship exists between the positions of the leafing node and the rooting node, basically N (the number of leaves) to N - 3. Prior to the 4th leaf period, rooting nodes develop half a leaf position earlier than leafing nodes, but after the 4th leaf period, the rooting nodes tend to slow down as the leaf age increases (See Table 1, Diagram 17).

Diagram 16. Position, order and direction of roots

1. seed root
2,3,4,5,6, are all sheath nodal roots
[2,3,(Paired), 4,5,(paired)
6 in that order].

Table 1. Relationships among Rooting Nodes, Number and Leaf Age (Fujii 1957)

Rooting nodes	Number of roots	Thickness of roots (millimeter)	Leaf age at rooting
Seed root	1.0	0.64±0.06	--
Plumule sheath nodal root	5.0	0.88±0.04	1~2 leaf period
Incomplete leaf nodal root	6.3	0.53±0.04	2~3 " "
First leaf nodal root	8.0	0.65±0.06	4 " "
Second leaf nodal root	10.1	0.71±0.09	5 " "
Third leaf nodal root	11.8	0.75±0.12	6 " "

Roots emerging from different nodal positions are different not only in shape (number of roots and thickness) but also in function. The seed root and the plumule sheath nodal root are both temporary root systems of the seedling. Their main function is absorption of moisture, nutrients and "standing the seedling." Because the seedling cannot produce the plumule sheath nodal root before the first complete leaf has grown, any damage to the seed root at the time of removing the grains or forcing the seed to bud for too long will necessitate delaying rooting and standing the seedling until after the first complete leaf has emerged (generally requiring 4 to 6 days). This not only

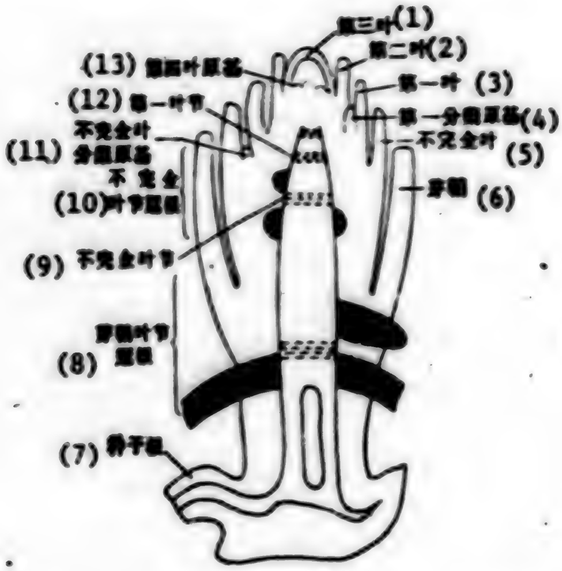


Diagram 17. Growth and differentiation of the organs during germination of the paddy rice seed (first leaf period) (Hoshigawa Kiyoshin 1971)

Key:
(1) Third leaf
(2) Second leaf
(3) First leaf
(4) First tiller primordium
(5) Incomplete leaf
(6) Plumule sheath
(7) seed root
(8) Plumule shealth leaf node crown root
(9) Incomplete leaf node
(10) Incomplete leaf nodal crown root
(11) Incomplete leaf tiller primordium
(12) First leaf node
(13) Fourth leaf primordium

delays rooting time but also may cause the buds to rot and the seedlings to die. Thus, to make sure that the seed root and the plumule sheath nodal root grow rapidly and can enter the soil completely and in time, forced budding must be uniform, the soil of the seed bed must possess appropriate hardness and, most importantly, aeration and the supply of oxygen must be sufficiently provided. This is because the growth of the root is mainly due to cell division. Cell division depends mainly upon synthesis of proteins and nitrogenous substances within the body of the seedling. Protein synthesis takes place only under oxygenic and aerate conditions. Protein synthesis is possible only when the nutrients in the endosperm are decomposed and transported and when large amounts of energy and nutrients are being produced. Thus, during the period when the seedling is rooting and standing, it must not be submerged in water nor be submerged for a long period (except when preventing frost damage). In general, it is best to keep the soil moist.

Growth of the bud and the root are different. This is because the growth of the plumule sheath is mainly due to elongation of cells and can take place

under oxygenic and anaerobic conditions. Under anaerobic conditions the plumule sheath extends even faster than under oxygenic conditions. Since the plumule sheath, like the leaves, also possesses pores and aerate tissues, it can grow rapidly under anaerobic conditions (when submerged under water) until it reaches above the water to absorb oxygen. This is a physiological adaptation to nature. This is the basis for the popular saying: "Water helps buds grow, dampness helps roots grow." Thus, prior to the second leaf period and especially before "showing green," the "seedling must be stimulated by drying" while the soil of the seed bed is kept moist. Irrigation, aeration and temperature are controlled. Although "stimulating the seedling by drying" is a successful method, it will prevent the seed from obtaining enough moisture if the seed is planted in sandy soil or when the weather is dry and the temperature is low thus making it difficult for the seed to bud and sprout. Under these conditions, the field must be irrigated to protect the seedlings and to prevent the seeds and buds from rotting. As the seedling grows to its second leaf period, the aerate tissues inside the body of the seedling gradually become complete and the amount of oxygen transported from the part of the seedling above ground to the roots increases. At this time, even if the seedling is submerged in water, the demand for oxygen by the roots can be basically satisfied. Thus in production, the seedlings can be irrigated by shallow water when they reach the second or third leaf period. When the seedling reaches its fourth leaf period, the root that emerges from the first leaf node and the roots that follow have a much stronger and absorptive strength than that of the plumule sheath nodal root and the incomplete leaf nodal root. The root emerging from the first leaf node and the roots that follow constitute the major root system for absorption of nutrients and moisture after the seedling is transplanted. This is the reason why in production, the appropriate seedling age for transplanting is set at a leaf age of between 5 and 6 leaves. The seedlings of the third leaf period are in the "weaning stage." Their rooting strength is poor and they easily die after transplanting or become stunted seedlings. Seedlings of the fourth leaf period have a weak rooting strength and cannot withstand abuse. They must be transplanted with soil attached.

Nutrients needed by the seedlings for rooting are mainly supplied by the leaves on the rooting nodes. For example, analysis of the "Ai nan zao No 1" at a leaf age of 4.7 shows such a relationship between supply and demand of nutrients. One of the reasons may be because of the simultaneous extension of the leaf and root three nodes apart. According to analysis, at 6/0 (6 leaves on the main stem, same for following designations), the leaves are in the period of extension and there is no accumulation of starch. At 5/0, the leaves begin synthesis but the leaf sheath is still extending and the accumulation of starch is minute. At 4/0, the leaf sheath has just established its shape and the leaf has not yet entered its peak functioning period. Although there is a definite accumulation of starch in the leaf sheath the amount is not large. At 3/0, the leaf ceases to grow. Photosynthesis is active at this time and the amount of nutrients being exported is small, therefore the starch content is high. At 2/0, the amount of starch in the leaf sheath visibly drops. This is the time when the second node begins to root (N- 3).

The starch in the leaf sheath is being transported to the root in large amounts to satisfy the nutritional needs of rooting.

The roots that emerge from the nodes on the stem are generally called crown roots. Generally there are 7 to 12 nodes that can root as determined by the number of leaves on the main stem of the different varieties). Because the underground nodes of the stem are short and the crown roots emerge from bottom to top one after the other, a concentrated fibrous root system is formed.

n. Weaning Fertilizers and Their Effectiveness

As the seed germinates, buds and roots, the amount of starch and nutrients stored in the endosperm lessens day by day. Careful observations made by Tan Shang (2905 0006) (1951) show that in general the starch stored in the endosperm is basically used up before the third leaf period (Diagram 18 and Table 2) and the seedling begins its independent vegetative period. This period is called the "weaning" stage in production.

Diagram 18. Leaf age of the paddy rice seedling and consumption of nutrients in the endosperm

Key: (1) endosperm (4) first leaf period
(2) embryo (5) second leaf period
(3) incomplete leaf period (6) third leaf period

Table 2. Leaf Age and Amounts of Stored Material Remaining in the Endosperm

Leaf	Dry Substances (mg)		Percentage of Remaining Endosperm
	Organs	Endosperms	
0		18.0	100.0
Incomplete leaf	3.6	12.3	68.3
1.2	4.6	11.4	63.0
1.5	6.0	8.5	47.2
2.2	12.0	1.5	8.3
2.6	15.8	0.8	4.4
3.0	16.1	0.0	0.0

At the third leaf period, the seedling which has already acquired three green leaves and a good root system begins to live independently by synthesis and changes from a heterotrophic stage to an autotrophic stage. This is a major turning point in the physiology of the seedling and the key period to cultivating strong seedlings and preventing seedlings from rotting.

When the seed begins to bud, its carbon and nitrogenous nutrients are totally self sufficient. In particular, the amount of carbon (in the form of hydrocarbons) is more than self sufficient. However, the rice grains contain lesser amounts of stored protein, generally constituting about 8% of the weight of the seed only and frequently the need for growth of the seedling cannot be satisfied. It has been determined that two days after the seed germinates, drastic hydrolysis of protein begins and intensifies until it reaches a peak on the sixth day. On the eighth day (about the period of one leaf and one new leaf), hydrolysis of protein is nearly complete. In early spring when temperatures are low and when the seedling has only one or two leaves, supplementary supplies of nitrogen must be provided externally in time, otherwise the seedling will grow thin and weak. Thus in production, the beginning period of sidedressing of nitrogen fertilizer is usually moved ahead from the "weaning" period (at the third leaf period) to the period of one leaf and one new leaf. In this way, the deficiency of nitrogen in the body of the seedling can be supplemented to stimulate the strong and healthy growth of the seedling and at the same time to prevent any weakening in the supply of nitrogen during the third and fourth leaf period so that the seedling is kept in a period of "having sufficient nitrogen to increase formation of sugar." This greatly eases the difficulty in the demand and supply of nutrients during this period and increases the seedling's resistance to unfavorable external conditions.

After application of nitrogenous fertilizer and when the nitrogen enters the body of the seedlings, a definite amount of sugar is consumed for synthesis of protein and chlorophyll. Thus after the seedling absorbs nitrogen, the color of the leaves darkens and growth speeds up. These are the immediate results from application of nitrogen called "receiving nitrogen and consuming sugar." Following these effects, the clorophyll in the leaves of the seedling increases, the area of the leaves expand, photosynthesis intensifies. As a result the amount of photosynthetic products-sugar and starch increases, achieving the stage of "having sufficient nitrogen to increase formation of sugar." (Diagram 19 and Table 3, 4).

It can be seen from Tables 3 and 4 that after application of nitrogen as a weaning fertilizer, the amount of chlorophyll increases, synthesis of sugar (carbohydrates) and accumulation of dry substances in the seedling speeds up and the content of sugar is increased. However, the application of nitrogen as a weaning fertilizer is based on the assumption of a rapid loss of weight of the endosperm (receiving nitrogen and consuming sugar). In actual application, the conditions of cultivation must be observed. Where fertility is low (such as an absence of base manure) and when the seedling age (such as 30 days) is relatively short, application of weaning fertilizers during the

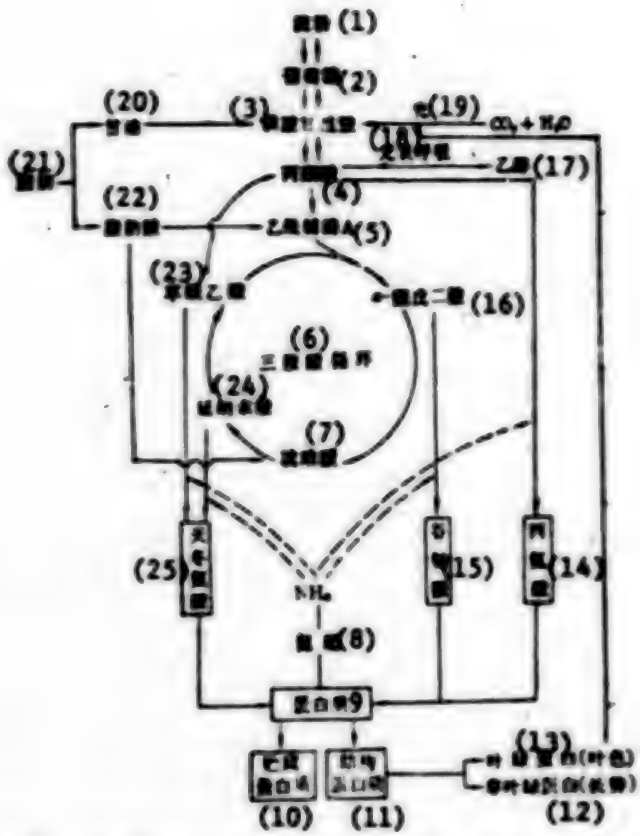


Diagram 19. Cycle of Nitrogen and Consuming Sugar and Nitrogen and Increasing Sugar

Key:
(1) starch
(2) glucose
(3) phosphoglyceric acid
(4) pyruvic acid
(5) acetyl CO A
(6) Tricarboxylic acid cycle
(7) Succinic acid
(8) nitrogen fertilizer
(9) protein
(10) stored protein
(11) structural protein
(12) non-chlorophyll protein (growth trend)
(13) chlorophyll protein (leaf color)
(14) proprionic acid
(15) glutamic acid
(16) α-ketoglutaric acid
(17) ethanol
(18) anaerobic respiration
(19) light
(20) glycerine
(21) fat
(22) fatty acid
(23) oxaloacetic acid
(24) fumaric acid
(25) aspartic acid

Table 3. Effect of Sidedressing of Nitrogen Fertilizers at the One Leaf and One New Leaf Period Upon the Dry Weight of the Seedling and Endosperm (Zhou Xie (0719 3610) et al 1976)

Leaf Age at Time of test	Treatment	Dry weight (mg/plant)			Remaing weight of seed (milligram/seed)
		part above ground	under-ground part	total dry weight	
One leaf and One New Leaf Period (April 13)	Before side-dressing	3.63	0.83	4.48	16.10
Two leaf and one new leaf period (April 18)	Application of nitrogen at one leaf and one new leaf period	9.03	2.58	11.61	7.63
	Without application of nitrogen	7.73	2.20	9.93	11.33

Remark: Variety tested: "Ainanzao No 1."

period of one leaf and one new leaf and another application at the third leaf period are appropriate. Where fertility is high and when the seedling age is older, application of weaning fertilizers would be more appropriate at the second leaf and one new leaf period.

E. External Causes that Affect Growth of Seedling

1. Temperature

Temperature greatly affects the growth of the paddy rice seedling. Studies by Yan Yurui (0917 5148 3843) (1956) under isothermal conditions indicate the lowest temperature for seedling growth is 12°C, the highest temperature is about 40°C and the most appropriate temperature is about 32°C (Diagram 20). If the temperature is below 10°C to 12°C or higher than 42°C, the roots and the buds will stop growing.

In cultivation, temperatures above 0°C and below 10°C often cause frost [sic] damage. Less serious frost [sic] damage is harmful to cultivating strong seedling and more serious frost damage may lead to rotting of the seedlings and death of sprouts.

Studies indicate that subjecting the paddy rice seedling a week after germination under temperatures of 3°C to 5°C for 5 to 7 days will cause the following physiological changes in the young paddy rice seedling:

Table 4. Eff[illegible] of Application of Weaning Fertilizers at Different Periods Upon the Content c[illegible]ar, Nitrogen and Chlorophyll in the Seedling
([illegible]ang Academy of Agricultural Sciences, Institute of Crops, Paddy Rice Cultivation Physiology Group, 1976)

Test subject	Comparison	Periods of Application of Fertilizers					
		one leaf one new leaf	two leaves one new leaf	three leaves	four leaves	one, three leaves	two, three leaves
sugar	953.95	1394.77	1465.06	1373.54	934.06	1740.55	1639.20
nitrogen	69.41	105.13	128.98	95.10			
chlorophyll	2.90	2.90	3.09	3.19			

Remark: (1) Analysis is based on guangluai No 4 at seedling age of 30 days. Unit of dry weight of sugar and nitrogen is milligram/100 plants. Unit of chlorophyll content is milligram/gram fresh weight.

(2) Total amount of fertilizers applied was 12 jin of ammonia sulphate per mu. When fertilizers were applied twice, 4 jin/mu were applied the first time and 8 jin/mu were applied the second time.

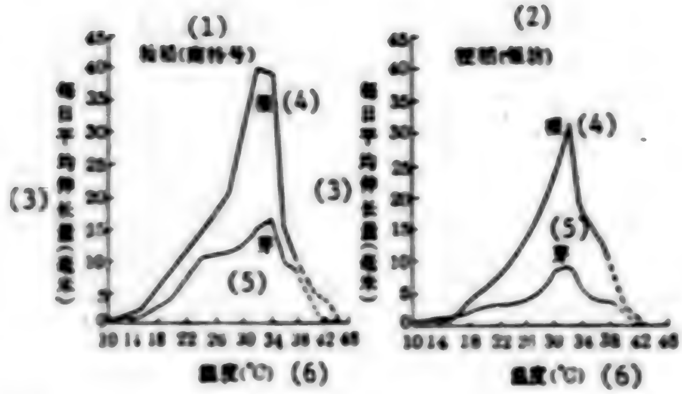


Diagram 20. Daily Average Length of Extension of Young Root and Young Bud Under Different Temperatures. (Note: Dotted line indicates two-day average length of extension)

Key:
(1) Xian Rice (Nante)
(2) Geng Rice (Yinfang)
(3) Daily average length of extension (millimeter)
(4) root
(5) Temperature °C
(6) Bud

(1) Intensity of photosynthesis of the young seedling drops. It has been determined that at a temperature of 25°C, the intensity of photosynthesis of the young paddy rice seedling is 15.99 milligrams of carbon dioxide/gram dry weight/hour while the intensity of photosynthesis of seedlings under freezing temperatures is 12.90 milligrams of carbon dioxide/gram dry weight/hour.

(2) The intensity of respiration visibly intensifies. Experiments conducted by Chen Quanlong (7115 2938 7893) (1963) indicate that the intensity of respiration of the young seedling visibly intensifies when subjected to freezing [sic] temperatures of 3°C to 5°C for 2 to 4 days. But when the number of days of freezing increases, the intensity of respiration begins to drop. The intensity of respiration of the roots begins to drop earlier than that of the leaves (Diagram 21).

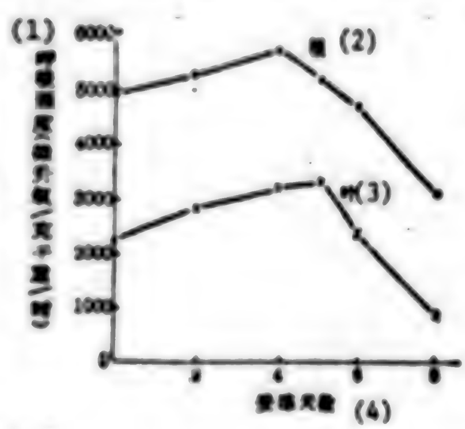


Diagram 21. Effect of low temperatures upon intensity of respiration of young paddy rice seedling.

Key:
(1) Intensity of respiration (microliter oxygen/gram dry weight/hour)
(2) root
(3) leaf
(4) number of days of freezing [sic]

Will the intensification of respiration of the young paddy rice seedling caused by low temperatures provide more energy? Chen Quanlong (1963) used a calorimeter to measure the conversion of energy and showed (Table 5) that under normal temperatures, the energy released by respiration can accumulate (3.1 - 7 calories/gram dry weight/hour). Under low temperatures the amount of energy released by respiration is less than that which should have been released by 0.6 - 1.0 calorie/gram dry weight/hour. The enzymic method also showed that under normal temperatures each gram of dry weight of young seedling can release 0.328 milligrams of ATP while under low temperatures only 0.098 milligrams is released. Further studies indicated that reduction in the amount of released energy was caused by "idle spinning" (expending of material without releasing energy) due to coupling of decomposed oxidized phosphate under low temperatures. In general, low temperatures cause consumption of material in the process of respiration without the release of energy.

Table 5. Measuring Thermal Conversion in the Paddy Rice Seedling

处 (1) 理		(1) 放出热量 (卡/克干重/时) (6)	(2) 应释放的热量 (卡/克干重/时) (7)	相差 (8)	$\frac{(2)}{(1)}$的百分比 (%) (9)
(2) 低温	(4) 二叶期	28.2	29.2	− 1.0	104
	(5) 三叶期	19.3	19.8	− 0.6	104
(3) 对照	(4) 二叶期	29.6	22.6	+ 7.0	86.0
	(5) 三叶期	23.4	20.3	+ 8.1	86.5

Remark: The temperature during the two leaves period was 30°C.
The temperature during the three leaves period was 25°C

Key:
(1) treatment
(2) low temperature
(3) comparison
(4) two leaves period
(5) three leaves period
(9) $\frac{2}{1}$ Percent
(6) (1) Amount of heat released (calorie/gram dry weight/hour)
(7) (2) Amount of heat which should have been released (calorie/gram dry weight/hour)
(8) different

(3) The ability of the roots to absorb water and fertilizers drop. Chen Quanlong et al (1962) showed by experiment that low temperatures lower the activity of the root system and lessen the ability of the root system to absorb water and minteral elements. Thus, when freezing young seedlings are suddenly placed under high temperatures, the moisture content in the rice seedling often loses equilibrium (Table 6) (the intensity of evaporation is stronger than the intensity of absorption) and the plants wither while still green.

Table 6. Loss of Equilibrium of Moisture in Seedling Damaged by Low Temperatures

Treatment	Evaporation (mg/hr)	Absorption (mg/hr)	Difference	Intensity of Evaporation (gram/meter^2/hr)
low temperature	35.8	32.5	− 3.3	38.8
comparison	56.6	60.7	+ 4.1	52.5

(4) Abnormality of Nitrogen Metabolism

Chen Quanlong (1962) showed by experiment (Table 7) that low temperatures above 0°C cause protein to decompose, enzymic activity to intensify and synthesizing enzymic activity to weaken as manifested by a lowering of the content of the total amount of nitrogen in the plant and the amount of protein nitrogen and an increase in the amount of amino nitrogen and ammoniacal nitrogen. As a result, a lot of ammonia is accumulated in the young seedling.

Table 7. Effect of Low Temperatures Below Zero Upon Nitrogen Metabolism in the Young Paddy Rice Seedling

(1) 处理	(4) 总氮	(5) 蛋白氮		(7) 非蛋白氮		(8) 氨基氮		(9) 氨态氮		(10) 蛋白分解酶的相对活性
		绝对值* (6)	%	绝对值 (6)	%	绝对值 (6)	%	绝对值 (6)	%	(6)
(2) 对照	56.96	48.242	84.69	8.718	15.31	3.062	5.37	0.1481	0.262	100
(3) 低温	45.0	36.298	80.66	8.702	19.34	4.424	9.83	0.2166	0.483	134

* Unit of absolute value is milligram/gram dry weight

Key:
(1) Treatment
(2) Comparison
(3) Low temperature
(4) Total nitrogen
(5) Protein nitrogen
(6) absolute value*
(7) Nonprotein nitrogen
(8) Amino nitrogen
(9) Ammoniacal nitrogen
(10) Relative activity of Proteinase

(5) Permeability of protoplasm increase

Studies by Lu Dingzhi (7120 1353 1807) (1965) showed that permeability of the protoplasm of the cells of the young paddy rice seedling is affected by low temperatures. Changes are not obvious during the period when the young rice seedling is subjected to low temperature but after the seedling has been subjected to low temperatures and when the temperature rise again, the permeability of the protoplasm rises drastically and the longer the seedling is

subjected to low temperatures the more drastic the increase in permeability. (Diagram 22)

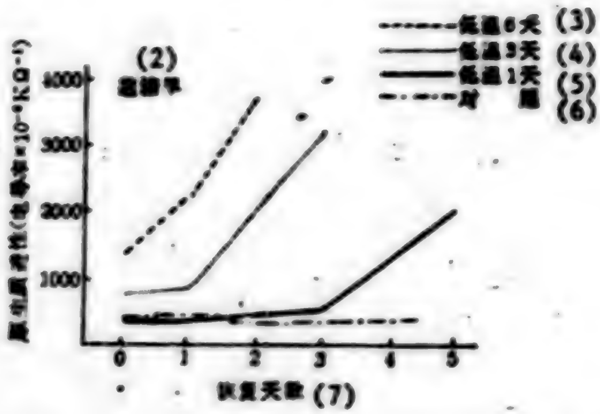


Diagram 22. Changes in permeability of protoplasm after low temperature treatment and rising of temperatures

Key: (1) Permeability of protoplasm (electric conductivity x $10^{-6}K\Omega^{-1}$)
(2) Liantangzao
(3) ------low temperatures lasting 6 days
(4) ......low temperatures lasting 3 days
(5) ______low temperatures lasting 1 day
(6) _._._.Comparison
(7) Number of days of recuperation

Low temperatures cause the permeability of the protoplasm to increase. This can be detected not only in the electric conductivity of the protoplasm but also can be proven by the leakage of substances from the young seedling. When a paddy rice seedling is placed in a temperature of 5°C for 36 hours, leakage of amino acid from the parts of the young root which have not yet lignified can be detected (Diagram 23).

In the Shanghai area, the major crop being damaged by low temperatrues above 0°C is early rice. In cultivating the seedlings of late season rice, seeds are sown in high temperatrues when the average daily temperature reaches 25°C and at noon the soil surface temperature of the seed bed can reach 40°C or above. If a thin layer of water is maintained over the seed bed, the water temperature may often reach 50°C or more, causing the phenomenon called "boiling the buds." Thus in cultivating seedlings during the high temperature season, the field should not be irrigated with a thin layer of water before or after noontime to prevent "boiling the buds" (Generally it is appropriate to drain the water from the seed bed.)

2. Oxygen

After the paddy rice seed has germinated, sufficient oxygen should be supplie' continually to benefit the growth of the seedling. Zhu Cheng (2612 3397)(1959) et al showed in his studies that with sufficient oxygen, the seed root extends rapidly (Table 8). Ten days after germination (under 22°C), 5 plumule sheath nodal roots emerge. Their length quickly extends to almost the same length as the seed root and branching roots emerge from these roots. With sufficient oxygen, growth of the part above ground is also rapid. Ten days after germination, the two young leaves and a leaf primordium of the plumule grow rapidly. The branching tissue at the tip of the stem continues to differentiate into two leaf primordia and a tillering primordium emerges from the axil of the first complete leaf and the incomplete leaf. But when the seedling is submerged in water and is under anaerobic conditions (where the oxygen concentration is 0 to 0.2%), only the plumule sheath grows. Ten days after germination, the original organs inside the embryo still remain and no new organs are formed. It can be seen from these experiments that the supply of oxygen is extremely important to the growth of the young seedling and directly affects the formation of the seedling.

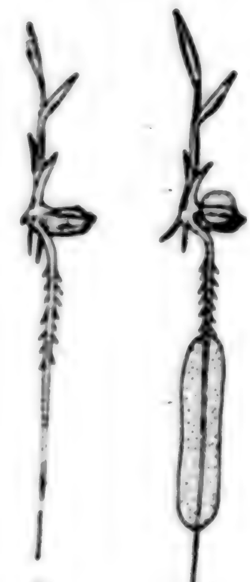


Diagram 23. Low temperatures cause leakage of amino acids from the young seedling of paddy rice.

1. The young seedling is placed in a temperature at 25°C for 36 hours.

2. The young seedling is placed in a temperature of 5°C for 36 hours.

Amino acids leaks out from the young root and the seed (Using a filter paper to soak up the amino acid leaking from the plant and testing with indene triketone, the amino acid shows red.)

Table 8. Speed of Growth of Seed Root Under Different Amounts of Oxygen Content

Concentration of Oxygen %	Length of seed root these number of days after germination (mm)			Multiple of the length of the seed root ten days after germination
	1 day	5 days	10 days	
0	0.28	0.92	10.0	36
5	0.28	16.2	42.4	150
21	0.28	32.5	74.2	266

The content of oxygen affects the growth of the seedling mainly because it affects the respiratory paths. Many studies indicate although germination of the paddy rice seed and growth of the plumule can tolerate anaerobic conditions and carry on anaerobic respiration under such conditions to obtain material and energy, normal germination of the paddy rice seed and healthy growth still require conditions in which oxygenic respiration is the major means of respiration. This is because an anaerobic respiration under anaerobic conditions, the efficiency of material transformation (Table 9) and efficiency of energy conversion (Table 10) are greatly reduced. More material and energy are needed to form 1 milligram of seedling. This is not beneficial to the growth of the paddy rice seedling.

Table 9. Efficiency of Material Transformation Under Different Oxygenic Condition* (Tang Peisong (3282 0160 2464 et al.,), 1959)

(1) (%)	(2) (毫克)	(3) (毫克)	(4) (毫克)	(5) (毫克)	(6) (%)	(7) (毫克)
(8)						
0~0.2	24.50	21.94	2.56	0.54	20.9	3.74
5.0	25.14	22.06	3.08	1.52	49.5	1.01
20.8	25.40	20.50	4.90	2.44	49.8	1.01
(9) 10 天						
0~0.2	24.60	19.44	5.16	0.55	10.7	8.38
5.0	24.62	15.04	9.58	5.24	59.6	0.68
20.8	24.78	13.40	11.38	6.50	57.1	0.75

$$\text{* Material transformation efficiency \%} = \frac{\text{Dry weight of organs}}{\text{consumed weight}} \times 100$$

Key:
(1) oxygen concentration (%)
(2) dry weight of original seed (mg)
(3) remaining dry weight (mg)
(4) weight loss (mg)
(5) dry weight of organs (mg)
(6) Efficiency of transformation (%)
(7) Dry weight of endosperm consumed for formation of 1 mg dry weight of seedling (mg)
(8) 5 days after germination
(9) 10 days after germination

In addition, under anaerobic conditions, the activity of amylolytic enzymes is reduced, the stored starch in the endosperm cannot be hydrolyzed in time and the products of hydrolysis cannot be transported to the embryo efficiently (Table 11). The growth of the young seedling is thus adversely affected.

Zhu Cheng (1959) also showed by experiment that the oxygen content affects the growth of different organs of the young paddy rice seedlings differently (Table 12).

Table 10. Effect of the oxygen content upon stored material in the paddy rice seed and the efficiency of energy conversion in the organs of the young seedling (Tang Piesong, et al., 1959)

含氧量 (1) (%)	(2) 原种子			(6) 剩下种子			器官 (7)			能量转化效率 $\frac{E_3}{E_1-E_2}\times 100\%$ (8)	形成1毫克干重器官所消耗热量 (卡) (9)
	干重 (3) (毫克)	每克干重含热量 (卡/克) (4)	含热量 (卡) (5) E_1	干重 (3) (毫克)	每克干重含热量 (卡/克) (4)	含热量 (卡) (5) E_2	干重 (3) (毫克)	每克干重含热量 (卡/克) (4)	含热量 (卡) (5) E_3		
萌发第5天 (10)											
0~0.2	24.52	3956	97.0	21.94	4267	93.62	0.54	4296	2.31	68.34	1.98
5	25.14	3956	99.45	22.06	4119	90.87	1.52	4401	6.69	77.97	1.20
20.8	25.40	3956	100.48	20.50	4125	84.79	2.44	4316	10.53	67.11	2.10
萌发第10天 (11)											
0~0.2	24.60	3956	97.32	19.44	4343	84.43	0.56	4393	2.42	18.77	19.00
5	24.52	3986	97.00	15.64	4113	64.33	5.29	4317	22.84	69.91	1.80
20.8	24.78	3956	98.03	13.40	4172	55.90	6.50	4179	27.16	64.47	2.30

* The variety Yinfang was used and the data listed were average values for 50 seedling plants.

Key:
(1) oxygen content %
(2) original seed
(3) dry weight (mg)
(4) caloric content per gram dry weight (caloric/gram)
(5) caloric content (caloric)
(6) remaining seeds
(7) organs
(8) energy conversion efficiency
(9) caloric expended for formation of 1 mg dry weight of organs
(10) 5 days after germination
(11) 10 days after germination

Table 11. Relationship between consumption of starch and different oxygen content (Dai Yunling (2071 0061 3781), 1960)

Oxygen content	Starch consumption %*		
	1 day after germination	5 days after germination	10 days after germination
0.2	0	2.8	6.2
5.0	0	5.3	15.7
20.8	0	6.4	25.0

* Calculated from the area of the central section of the seed.

Table 12. Comparison of the Growth of Various Organs Under Different Oxygenic Conditions

Oxygenic conditions %	Plumule sheath: length of sheath (mg)	Plumule sheath: length of of cell of epidermis (micrometer)	Incomplete leaf: length of leaf (mg)	Incomplete leaf: length of cell of flesh of leaf (mm)	Seed Root: length of root (mg)	Seed Root: length of cell of epidermis (mm)
0 0.2	63.2	263.7	9.5	67.0	10.0	87.8
5	20.0	1487	40.1	79.6	42.4	83.4
21	16.6	95.1	53.5	74.0	74.2	97.6

Remark: Results of observation 10 days after germination

Under anaerobic conditions, the growth of the root is greatly limited while the growth of the plumule is stimulated. This is because the plumule sheath is a preliminarily formed organ which has already differentiated and is completely formed in the embryo. Its growth depends mainly on cellular elongation; cellular elongation is mainly a process of moisture absorption by the cell. Material and energy needs are few. Therefore, under anaerobic conditions, it can complete its growth process. But the growth of the root and differentiation of new organs are different. They are newly formed organs. The growth of these organs takes place mainly by cell division. The process of cell division involves multiplication of nucleic acid and protein. It requires sufficient material and energy and can only take place under conditions in which the supply of oxygen is sufficient and only via the path of oxygenic respiration. Thus we can see from Table 12 clearly that as the content of oxygen increases, the root increases in length but the length of the cells does not change visibly.

Oxygen affects the growth of the young paddy rice seedling generally during the early period. After the plumule sheath extends above the water surface, oxygen is able to enter through the pores and aerate tissues leading to the roots where it is used by the root system for oxygenic respiration. Thus after paddy rice "shows green," the field can be irrigated with a layer of water.

3. Light

An important condition for cultivating strong seedling is the satisfaction of their need for light. Only under conditions of sufficient sunlight with the addition of fertilization and irrigation can the seedlings manufacture and accumulate large amounts of nutrients via photosynthesis for the healthy growth of the root and leaves and for further differentiation of the primordia of the root and leaves. Insufficient light causes the seedling to become thin and weak, the leaves on the lower part of the plant to wither early

and the roots to develop poorly. Even if a lot of fertilizers is applied, the seedling will not be able to grow into a strong seedling but will remain thin and long.

At present, we are still unable to control natural light. But we can adjust the amount of sowing to satisfy the need for light by the seedling. It is generally believed that sparse sowing is an important link in cultivating strong seedlings. Only by assuring a definite light condition for the seedling can the growth of the seedling be stimulated so that the seedling can grow into a strong seedling. Studies indicate that before the seedling age reaches the four leaves period, a light intensity of 35,000 meter-candles is sufficient for full photosynthesis in sparsely sown as well as densely sown fields. A saturated light condition clearly exists. This is also clearly indicated by the growth curve represented by the dry weight of the plant. At this time, the dry weight of the seedling plant does not vary. But when the seedling grows to the 4.6 leaves period, the more densely sown seed beds will have a higher light saturation point but the amount of photosynthesis of the individual plant reduces. When the seedling reaches the 5.2 leaves period, light provided by natural light sources for full photosynthesis in densely sown seed beds is insufficient. As the photosynthetic ability of the individual plant begins to weaken, the dry weight also begins to lessen and a visible difference (in dry weight) emerges. When the seedling reaches the 6 to 7 leaves period, the difference becomes more obvious. This is to say, even though the number of seedlings per mu in a densely sown seedbed is large, the amount of unit area photosynthesis is lower than that in sparsely sown seedbeds and the dry weight of the individual seedling is much lower than that of sparsely sown seedlings. Thus, sparse sowing in the seedbed can elevate the quality of the seedling and is beneficial to the cultivation of strong seedlings. In recent years in the middle and lower reaches of the Chang Jiang area, some provinces and cities have extensively utilized the two stage seedling cultivation method. One of its superior points is that it provides different vegetative surfaces to the seedlings according to the size of the seedling so that photosynthesis can take place fully, resulting in an increased accumulation of dry substances and an improved quality of seedlings better than that of sparsely sown seedlings with a long seedling age. Seedlings grow even more healthily and strongly. Thus, the amount of sowing must be measured according to the conditions at the time of transplanting. These [environmental] conditions must not seriously limit growth because of insufficient light or cause the seedlings to grow abnormally long. This requires that the coefficient of leaf surface area in the seedbed at time of uprooting the seedlings for transplanting is not more than 3.5. Appropriate adjustments can be made under different conditions according to the length of the seedling age (the leaf age), climatic changes and different methods of seedling cultivation.

In general, sowing too densely and improper stimuli from improper light conditions will cause irreparable damage which cannot be corrected by any other measure implemented in the seedbed. Only by correctly grasping the proper amount of sowing can the foundation for cultivating strong seedlings be laid.

F. Adjusting Levels of Carbon and Nitrogen in the Seedling

Leaves of seedlings transplanted at the proper seedling age but damaged during uprooting for transplanting, or leaves of seedlings whose bodily moisture has lost its equilibrium due to sudden changes in environmental conditions may not extend normally. Whether the leaves can extend normally depends to a large degree upon the condition of rooting. Thus the rooting strength and strength of resistance to adversity must be increased prior to transplanting so that the seedling can meet the demands of early greening and early tillering after transplanting.

Seedlings uprooted for transplanting will almost always have broken roots. Old roots over 6 centimeters long that remain will generally die soon after transplanting. Only white, short roots shorter than 2 centimeters can continue to grow and absorb nutrients and moisture. If the seedling's rooting strength is strong, the seedling will be able to produce many new roots and root rapidly after transplanting. Conversely, if the seedling's rooting strength is weak, rooting will be slow and new roots will be few.

Studies have shown that two factors determine the seedling's rooting strength. One is the number of primordial roots on the stem of the seedling. The number usually increases from bottom to top node by node. Seedlings at the time of transplanting usually will have at least reached the five leaves period therefore the number of primordial roots is large. The other factor is the levels of carbon and nitrogen within the body of the seedling, especially the level of nitrogen. This is because differentiation of the primordial roots and reproduction of the cells of the roots all require sufficient amounts of nitrogenous organic matter such as protein and nucleic acid. When the nitrogen level is low, the rooting strength will be weak even though the seedling is at a proper age. When the nitrogen level is high, the primordial roots wi'' differentiate plentifully and the reproduction of cells of the root will be rapid. A large number of roots will be able to emerge 3 to 4 days after ansplanting in the large fields and early greening will be stimulated. Although the relationship between rooting strength and the level of carbon is not as close as that between rooting strength and the level of nitrogen, the level of carbon serves a definite function. Carbohydrates are the major sources of energy during the peak growth period of the cells of the root and are involved in the formation of the material of the cellular walls (such as cellulose, semifiber and pectin). In particular, the hydrocarbons in the leaf sheath on the rooting nodes are specifically used for rooting from that node. If the leaf sheath does not have a storage of starch, then rooting will also be affected.

Seedlings must possess a strong rooting strength and a strong resistance to adversity after transplanting. After transplanting and before the new roots emerge in abundance, the seedlings must be able to resist low temperatures and strong sunlight. Thus, the carbon level within the body of the seedling must be high, the osmotic pressure of the cells must be high, the content of bonded water must be high and the seedling roots must be aged and healthy.

The leaves of this kind of seedling will not easily dry up and wilt under high temperatures and strong light after the seedling is transplanted, but often this type of seedling has a poor rooting strength and greens slowly.

Things, however, always develop according to the law of the unity of opposites. The metabolism of carbon and nitrogen in the body of the seedling depend on each other and limit each other. When the nitrogen content in the seedling is high, often the amount of sugar is small. When the amount of sugar is large, the amount of nitrogen seems insufficient. We must solve this contradiction and lead the growth towards reasonable development. Thus, in production at present, application of fertilizers at different intervals is a method used to regulate the relationship of nitrogen and carbon in the body of the seedling. Based on the application of weaning fertilizers during the early period of growth (one leaf and one new leaf), the seedling should be observed at the three and four leaves stage to determine whether or not a light application of relay fertilizers is needed so that 6 to 7 days prior to transplanting the color of the leaves turns light and sugar accumulates in the body of the seedling. Three to four days before uprooting for transplanting, rising fertilizers are applied. After the nitrogen has been absorbed into the body of the seedling, the leaves change color. Their the seedling can be uprooted and transplanted before the leaves change to a yellowish color (when nitrogen is increased but sugar has not been expended in large amounts). At this time, the body of the seedling contains a definite level of nitrogen; the sugar that had been accumulated previously has not been overly expended; the content of both nitrogen and carbon remains at a high level. The seedling thus has a strong rooting strength and a strong resistance to adversity.

IV. Rooting Strength and Growth of Seedling of Hybrid Rice

Because germination and early growth of paddy rice are most closely related to the activity of amylolytic enzymes and the amylolytic enzymes of the hybrid paddy rice seedling are visibly more active than those of ordinary varieties, the hybrid paddy rice seedling manifests visible growth superiority. Guangxi Agricultural College sowed hybrid rice "Nanyou No 2" and "Zhenzhuai No 11" at the same time and managed the seed beds of the two crops the same way. The results were investigated. The dry weight of the portion of the hybrid "Nanyou No 2" plant above ground was heavier than that of the "Zhenzhuai No 11" by 11.1 milligrams. The number of white roots of the hybrid plant was more than that of "Zhenzhuai No 11" plant by 2.9 roots and the dry weight of the root of the hybrid plant was 3.02 milligrams more than that of the "Zhenzhuai No 11" plant.

Production practices over the past few years have shown that the rooting ability of hybrid paddy rice rice seedlings is stronger than ordinary varieties. For example, the Shanghai Plant Physiology Institute, Photosynthesis Laboratory et al (1977) conducted an experiment on transplanting of late season rice. The roots of the seedling were completely cut off. The seedling was cultivated in a water culture by hydroponic methods for 5 days to observe

the rooting strength of the seedling (Table 13). The results show that the rooting strength and the number of the roots of the hybrid rice seedling are higher than ordinary varieties. Thus, after transplanting, the hybrid seedling has a stronger ability to absorb moisture and nutrients than ordinary varieties and can green rapidly and tillers fast and plentifully.

Table 13. Comparison of Rooting Strength of Hybrid Rice Seedlings and Ordinary Rice Seedlings

Varieties	Average number of roots (roots/plant)	Average length of roots (centimeter/plant)	Rooting strength (centimeter/plant)	Remarks
Nanyou No 3	22.8	8.9	202.92	rooting strength = number of roots x length of roots (centimeter) "Nanyou No 3" is a hybrid rice.
IR-661	11.4	8.5	96.9	
Erjiunan No 1	15.3	8.8	134.64	
Jianong 485	12.4	9.9	122.76	
Guangluai No 4	10.3	7.7	79.31	

V. The Reasons That Seedlings Rot and Methods of Prevention

Rotting seedling is the general term for rotting seeds, rotting buds and rotting sprouts. Over the years during the period of cultivating early rice, rotting seedlings often occurred. Rotting seedlings not only cause damage to rice seed but also cause missing plants, disturbance in the arrangement of varieties, delays in crop calendars and affect maturity and high yield. Thus, understanding the causes of rotting seedlings and taking effective measures to prevent this are the keys to cultivation of strong seedlings.

Rotting of the seedlings is related to the duration of low temperatures and dampness and rain during the period of seedling cultivation. It is usually serious in years of low temperature and years having long periods of dampness and rain, and vice versa. Sun Linshu (1327 7792 2579) (1963) experimentally subjected seedlings to natural low temperatures (average daily temperature above 10°C, lowest daytime temperature between 3°C and 7°C) for 1, 3, 6, and 9 days and then moved the seedlings into a green house (25°C to 30°C) to stimulate the seedling and revive growth. It was discovered that while the seedling was being subjected to low temperatures there were no external changes. But during the processes of reviving growth in the green house after being removed from the low temperature conditions, the symptoms of low temperature damage emerged and differences resulting from different durations under low temperature conditions and differences due to different leaf ages became obvious (Table 14).

Table 14. Rotting Roots Affected by Low Temperatures for 9 Days

Leaf age at time of low temperature	Rotting seedling %	Symptoms	Remarks
Budding stage	9.0	Plumule turns yellowish brown	Variety: "aijiao Nante"; Low temperatures 3°C to 7°C; Duration of 9 days
First leaf stage	34.0	Color of leaves turns yellow, brown spots emerge	
Second leaf stage	98.0	New leaf is partially curled and is dirty green in color	
Third leaf stage	100.0	New leaf is curled and is dirty green in color	

But are low temperatures the main cause of rotting seedlings? Practice shows that under the same low temperatures, rotting seedlings seldom occur in dry seedling cultivation but dead seedlings often occur. The opposite occurs in cultivation of seedlings in water; rotting easily occurs but there are very few dead seedlings. It can thus be seen that the causes of rotting seedlings are complex. Different types of rotting are the results of different causes. The following analyzes the three major types of rotting seedlings, rotting seeds, rotting buds and dead sprouts, explains the causes and presents the methods of prevention.

A. Rotting Seeds

Rotting of the seeds refers to the type of rotting of a seed which has not germinated after the seed is sown in the seed bed. One of the causes is that the seed loses its ability to live which is often caused by an overly mushy or an overly hard seedbed. In the first case the seed is drowned and rots. In the second case the seed lacks water and begins to rot because of exposure. The way to prevent this is to elevate the quality of the seed as well as the seedbed.

B. Rotting Buds

Rotting of the buds is the phenomenon occurring after sowing but before showing green. The bud dies before showing green. The root cause is the hampered growth of the root system allowing such microorganisms as saprogens to enter the grain which then rots. Since there are many reasons that can hinder the

growth of the root system, comprehensive measures must be taken specifically to prevent rotting buds.

1. Rotting of the bud due to a lack of oxygen

After the grain is sown, the key is to have it root rapidly and establish itself firmly in the soil. Since the growth of the root depends on cell division under oxygenic conditions, the submerged condition where the oxygen content is not more than 0.3% - 0.5% constitutes conditions of insufficient oxygen. Under these conditions, the efficiency of material transformation and energy conversion is lowered and the growth of the root is hampered. This causes the bud to lodge because the roots have not emerged rapidly enough and allows bacteria to enter the bud causing it to rot. Thus, in the process of cultivating seedlings in water or in moist conditions, the seedbed should be kept moist but should not be submerged under water (There should be water in the seedbed trenches but none on the surface of the sedbed) after sowing and bursting of the seeds. This is an important measures to prevent rotting of the buds.

2. Rotting of the buds caused by persistent low temperatures

As already mentioned above, persistent low temperatures below 10°C and above 0°C will cause the growth of the root system to stagnate, lessen the activity of the root system and confuse metabolism. All of these are important causes of rotting of the buds. But are there causes other than low temperatures? Zhou Xie (1976) conducted an experiment placing seeds that have already germinated in a daytime temperatures of 14°C and a nighttime temperature of between 2°C and 4°C for 7 days (under damp and oxygenic conditions). It was discovered that seed buds of disinfected rice grains planted in disinfected soil do not rot. Seed buds of seeds not disinfected and planted in soil not disinfected had a 75 percent rate of rotting buds (Table 15). It can thus be seen that low temperatures cause the vitality of the bud to be reduced, allowing pathogenic bacteria in the soil and on the grain husk to cause damage and rotting. Since these pathogenic bacteria are all weakly parasitic, they damage the seed bud and cause the bud to rot only when the growth of the seed embryo ceases or stagnates and vitality reduces. Damage can be avoided if the seed can root fast and the sprout can grow and establish itself fast.

Table 15. Effect of Low Temperatures and Pathogenic Bacteria Upon Rotting of the Paddy Rice Bud

Treatment	Low temperatures lasting 7 days (daytime temperature 14°C/nighttime temperature 2°C-4°C)	Disinfected grain seeds (2% formaldehyde 3 hrs.)	Disinfected soil (high temperature)	Percentage of rotting buds %
1	+	+	+	0
2	+	+	-	54.0
3	+	-	+	10.5
4	+	-	-	75.0

Remarks: + indicates existence of such conditions
- indicates non-existence of such conditions

3. Methods to prevent rotting of the bud

It can be clearly seen from the above that rotting of the bud is caused by a combination of low temperatures above 0°C but below 10°C, a lack of oxygen or pathogenic bacteria on the grain husk and in the soil. Therefore, we can find ways to prevent rotting of the bud and take appropriate measures.

(1) Forcing the germination of "strong buds and the growth of short roots" and preventing the breaking of the tips of the roots of the seed are basic measures to assure fast rooting.

(2) Sowing should be done timely in sunny weather at the end of cold weather and the beginning of warming trends. This will create conditions of sufficient temperature for rooting and increase the seedling's resistance to infection by pathogenic bacteria.

The lowest temperature for germination of the early xian rice (plumule sheath) is from 12°C to 14°C but the lowest temperature for rooting and budding (emergence of seed roots and leaves) is between 15°C and 16°C. Within the safe sowing period, the frequency of rain, sunshine, warm and cold weather in spring must be taken into consideration. Thus sowing seeds in sunny weather at the end of cold weather and the beginning of the warming trend when the highest daytime temperature can reach 19°C to 21°C or above will facilitate early rooting. If heating agents such as husk ask or fine soil are used to cover the surface of the ridges to raise the temperature higher (Table 16), rotting of buds can be better prevented (Table 17).

It can be seen from the table that by using heating agents such as husk ash and fine soil, the sprouting percentage can be increased by 10 percent to 18 percent over the sprouting percentage of using crushed soil and the percentage of rotting seedlings is lowered by 12 percent to 16 percent. The use of heating agents and husk ash also produces strong seedling growth, a developed root system and a good growth trend; while using crushed soil produces seedlings that grow poorly.

When cold air moving south covers the seedbed after seeds have been sown, the field can be covered with a flat thin plastic sheet to retain the temperature in the seed bed.

(3) Damp irrigation provides needed oxygen for rooting. Studies show at least 5 percent oxygen is needed for roots to grow but the content of oxygen (free) in water is only 0.3 percent to 0.5 percent, ten times lower than that needed by the root. Thus to assure firm rooting, the seedbed must be dried (fully filled trenches on sunny days and half filled trenches on damp days) so that oxygen can be supplied directly to the roots. This is an important way to prevent the buds from rotting. Short periods of irrigation to protect the seedlings are needed only during thunderstorms, frost and freezing. After the plumule sheath has emerged from the seedbed surface, the tip absorbs oxygen which is then transported to the root. Thus, irrigation in the seedbed must not cover the tip of the seedling and especially must not cover the tip of the seedling for a long time since doing so will affect the growth of the root.

Table 16. Heating Effect of Different Methods of Covering the Seedbed Under Different Weather Conditions (Jianhu County Weather Station, Jiangsu 1975)

(1) 项目	(8) 晴天								(9) 多云								(10) 阴雨							
	地面温度 (11)				5厘米地温 (12)				地面温度 (11)				5厘米地温 (12)				地面温度 (11)				5厘米地温 (12)			
	8时 (14)	14时	20时	平均 (13)	8时 (14)	14时	20时	平均 (13)	8时 (14)	14时	20时	平均 (13)	8时 (14)	14时	20时	平均 (13)	8时 (14)	14时	20时	平均 (13)	8时 (14)	14时	20时	平均 (13)
(2) 增温剂	18.4	33.5	17.6	23.2	15.6	25.4	20.0	19.6	10.2	22.1	10.6	14.3	8.8	17.0	13.5	13.1	14.8	19.6	13.1	15.8	14.4	17.0	14.0	15.1
(3) 砻糠灰	15.7	31.1	16.0	22.0	14.0	23.9	18.7	18.9	11.3	22.6	11.5	15.1	9.1	17.8	13.5	13.4	14.5	19.1	12.6	15.4	14.3	17.1	14.2	15.2
(4) 细土	18.1	29.1	16.7	21.0	13.7	23.2	18	[illegible]	[illegible]	10.9	22.6	11.0	14.8	8.9	16.9	13.2	13.0	14.0	18.2	11.8	14.7	13.5	16.4	13.5	14.7
(5) 绿肥(整)	16.8	26.5	16.6	20.0	13.6	22.4	18.1	18.0	10.1	19.5	11.5	13.6	9.4	16.5	13.5	13.1	14.0	17.5	12.5	14.7	14.2	16.1	13.5	14.7
(6) 绿肥(碎)	16.7	26.9	15.2	19.6	12.9	21.1	17.3	17.1	10.2	19.6	11.6	13.8	9.0	15.4	13.7	12.8	14.2	17.5	12.5	14.7	14.1	15.9	14.2	14.7
(7) 泥块头	17.5	29.3	15.9	20.9	13.5	23.6	18.4	18.6	9.9	20.9	11.0	13.9	8.9	16.0	12.6	12.8	15.5	15.5	13.2	14.8	13.5	16.4	14.0	14.8

Key:
(1) Item
(2) Heating agent
(3) Husk ash
(4) Fine soil
(5) Green manure (whole)
(6) Green manure (loose)
(7) Crushed soil
(8) Sunny day
(9) Cloudy day
(10) Damp and rainy day
(11) ground surface temperature
(12) temperature at depth of 5 centimeters
(13) average
(14) hundred (i.e. 0800, 1400, 2000)

Table 17. Relationship Between Growth of Seedling and Different Methods of Covering the Seedbed (Jianhu County Weather Station, Jiangsu, 1975)

(2) 处理 \ (1) 项目	(9) 播种期 (月/日)	(10) 出苗期 (月/日)	(11) 出苗率 (%)	(12) 苗高 (厘米)	(13) 三叶期 (月/日)	(14) 叶片数	(15) 叶宽 (厘米)	(16) 根数	(17) 烂秧率 (%)
(3) 增温剂	4/15	4/21	87.6	5.5	5/3	3叶一心	0.5	10	3
(4) 砻糠灰	4/15	4/22	83.3	6.4	5/6	〃	0.4	11	8
(5) 细土	4/15	4/23	81.8	6.3	5/6	〃	0.4	10	9
(6) 绿肥(整)	4/15	4/23	80.4	6.1	5/7	3叶 (18)	0.4	10	9
(7) 绿肥(碎)	4/15	4/26	66.7	5.0	5/8		0.3	9	19
(8) 泥块头	4/15	2/25	74.7	5.5	5/9	〃	0.3	9	25

Key:
(1) item
(2) treatment
(3) heating agent
(4) husk ash
(5) fine soil
(6) green manure (whole)
(7) green manure (loose)
(8) crushed soil
(9) sowing time(month/day)
(10) sprouting time (month/day)
(11) percentage of sprouting
(12) height of sprout (cm)
(13) three leaves stage (month/day)
(14) number of leaves
(15) width of leaf (cm)
(16) number of roots
(17) percentage of rotting seedling
(18) leaf (leaves)

(4) Remedies after rotting of the buds has occurred

If, in production, seeds were not sown in time during sunny weather, or if the seedbeds selected were not good and the soil of the seedbed was of poor quality or if low temperatures persisted for too long and the surface of the ridges was not dried in time to allow oxygen to reach the roots and the buds begin to rot, a mixture of 500 to 1 of dexon and 1000 to 1 of copper sulphate can be sprayed in large drops on the surface of the ridges (The surface of the ridges should be dried so that the soil can easily absorb the chemical solution. Three hundred jin can be sprayed over each mu) to kill the pathogenic bacteria in the soil. This remedy generally produces good results.

Since the cause of rotting buds combines many factors, comprehensive prevention should also be included in measures to prevent rotting of the buds.

C. Dead sprouts

Extension of the first complete leaf of the young paddy rice seedling indicates that the seed root and the plumule sheath nodal root have already entered the soil. The germination period thus ends and the seedling enters its sprouting stage.

A serious problem often occurs during the two leaves and three leaves periods of the early rice seedling, the leaves roll up and the seedling dies. The problem is most serious among dry cultivated seedlings, less serious among wet cultivated seedlings and least among seedlings cultivated in water.

There are two types of leaf rolling and dead sprouts. One is green withering and the other is yellow withering. Green withering occurs on new leaves. The new leaves begin to wilt and curl up or roll into an acicular shape. The base of the seedling does not rot. At the time of death, the chlorophyll has not been decomposed thus the seedling wilts and dies suddenly while still green. Yellow withering occurs when the old leaves begin to change their color to yellowish brown followed by the tender leaves. The base of the seedling rots. At time of death, the chlorophyll has already been decomposed, therefore the seedling withers and die slowly.

Leaf rolling and dead seedlings cause great losses in production. It is important to understand the cause of death and the conditions that cause such death and implement effective preventive measures to assure cultivation of strong seedlings of early rice.

1. Causes of leaf rolling and death of sprouts

Zhou Xie et al (1976) of the Jiangsu Agricultural College has studied this phenomenon for 4 years. He believes leaf rolling and dead sprouts are not the result of simple frost damage but are caused by damage from saprogenic bacteria entering the seedling during low temperatures when the young seedling's resistance is lowered (Table 18). That is to say, although low temperatures above 0°C reduce the resistance of the young seedling, without the

existence of pathogenic bacteria, the seedling will not die. Neither will it die when the temperature is suitable [for seedling growth] and the seedling's resistance is strong even though pathogenic bacteria exist. The possibility that the seedlings will die exists only when the temperatures above 0°C are low and when there are pathogens present.

Table 18. Analysis of the Cause of Leaf Rolling and Death of Sprouts

Treatment	Low temperatures daytime 25°C nighttime 5°C	Appropriate temperature daytime 25°C nighttime 20°C	Natural soil (not disinfected)	Soil Disinfected by heat	Dead Sprouts
1	-	+	-	+	-
2	+	-	-	+	-
3	-	+	+	-	-
4	+	-	+	-	+

Remark: (1) Table combines all factors of results of experiments conducted by Zhou Xie et al (1976)

(2) "+" represents existence of said conditions or said results
"-" represents non-existence of said conditions or said results

A test of the activity of the cells of different parts of the plant with a 1 percent TTC (2,3,5-tribenzo-tetranitrothiazole chloride) showed that when the leaves begin to curl, the young seedling's leaves, lef sheath and cotyledon still possess vitality and only the root loses its vitality (Table 19). Thus, the basic problem causing the death of the plant is the rotting root.

According to studies, the major pathogenic bacteria causing the root to rot is the Pythium sp.. Under low temperatures above 0°C, this species of pathogenic bacteria constitutes the majority of bacteria living parasitically on the root of the seedling with curled leaves. The roots of seedling being treated with such saprogen (in disinfected soil) will lose their vitality and the seedlings will wither when they are still green and die.

Since Saprogen is the cause of withering and death, what is the role of low temperatures above 0°C? Studies indicate low temperatures above 0°C weaken the metabolism of the young seedling (absorption and synthesis are suppressed), growth stagnates and resistance to disease weakens. Furthermore, low temperatures cause the permeability of the protoplasm to increase and nutrients to leak out from the roots, thus creating nutritive conditions for saprogens to enter the roots. At the same time, since the suitable temperature for the growth of saprogens is lower (bacteria can spread rapidly given temperatures

Table 19. Vitality of Cells of Normal Seedling and Seedling Having Curled Leaves (TTC dye, Zhou Xie et al, 1976)

(2) 活力 / 部位 (1) / 苗情 (3)	叶片 (7)	叶鞘 (8)	盾片 (9)	(10) 根	
				中柱 (11)	根尖 (12)
正常苗 (4)	+	+	+++	+	+
[illegible]卷叶苗 (5)	+	+	++	-	-
(6) 正常苗,用开水烫死	-	-	-	-	-

Remarks: TTC dye shows activity, +++, ++, + degree of redness, i.e., strength of cell activity; - indicates colorless, loss of activity of the cells

Key:
(1) Part of Seedling
(2) Vitality
(3) Seedling condition
(4) Normal seedling
(5) Seedling with curled leaves
(6) Normal seedling treated with hot water
(7) leaves
(8) leaf sheath
(9) cotyledon
(10) root
(11) root center root
(12) tip of root

above 4°C), the low temperatures also provide the [suitable] conditions for the saprogen. Finally, dry cultivation also provides good aerate conditions for the saprogens to grow. Thus, the longer low temperatures above 0°C persist, the stronger the intensity of such low temperatures and the better the soil's aeration the easier it is for saprogens to attack the seedling and the easier it is for the seedling to wither while green and die.

The weather pattern in the middle and lower reaches of the Chang Jiang is characterized by low temperatures, dampness and rain in early spring, then a sudden rise in temperatures and change to sunshine followed by low temperatures, dampness and rain. Thus, when the saprogens enter the root and cause the root to rot under low temperatures and during the damp and rainy period, the seedling does not manifest any symptoms. However, then the weather suddenly becomes sunny and the temperatures suddenly rise, the root system will show a loss of ability to absorb water and fertilizers. Metabolism of water "cannot be balanced," thus, often causing acute withering while green. If the seedling was subjected to persistently low temperatures, dampness and rain, then the part of the seedling above ground will yellow long before the weather becomes sunny and slowly withers.

2. Prevention of Curling and Dead Sprouts

Since curling leaves and dead sprouts are the results of saprogens that cause the root to rot under low temperatures, we can prevent the occurrence of such phenomena in two ways--by increasing and retaining temperatures and by disinfection and suppression of saprogenic bacteria.

(1) Irrigation: A suitable layer of water when the seedling reaches the age of one leaf and one new leaf on the one hand can suppress the growth of saprogens (growth of the hyphae is hampered because of a lack of oxygen) and on the other hand retain temperatures. It is important to create proper irrigational conditions in dry cultivation of seedlings to prevent seedlings from dying.

(2) Retention and increase of temperature: Ways must be sought to maintain the intensity and duration of the temperature in the seed bed above 15°C for early xian rice and above 13°C for early geng rice. When low temperatures occur, the method of "draining the water to increase the temperature" in the seedbed during the day and "irrigating water to retain the temperature" in the seed bed at night can be used as well as soil heating agents.

(3) Timely application of weaning fertilizers to increase the disease resistance of seedlings: Since the seedling has basically exhausted the stored nitrogen in the seed at the age of one leaf and one new leaf, weaning fertilizers consisting mainly of nitrogen must be applied at this time so that the seedling can "have sufficient nitrogen to increase sugar" and strengthen its resistance to disease (accumulation of carbohydrates in the body of the seedling is closely related to the plant's resistance to adversity).

(4) Use of soil disinfectants: All soil disinfectants that can kill or suppress saprogens can be used to prevent the seedlings from dying. At present, the most effective is dexon which has a low cost. The Jiangsu Provincial Yixing May 7 Agricultural University and other units used 700 parts to one of 65 percent dexon powder (2.5 jin per mu of seed bed). They mixed it with some water, stirred it into a paste, then diluted the mixture until the paste was completely dissolved and finally sprayed the solution over the seedbed or used a container with a spout to sprinkle the solution to kill the saprogens and prevent the seedlings from dying. Dexon should be sprayed around 4 or 5 o'clock in the afternoon after the seedbed has been drained dry in the morning. It should not be mixed or sprayed together with alkaline agricultural chemicals.

The fact that disinfectants can prevent the seedlings from dying is another proof that saprogen is the main pathogenic bacteria causing the seedlings to die.

(5) Remedies to save seedlings with curled leaves and dying seedlings: The basic cause of seedlings with curling leaves and dying seedlings is the rotting of the roots. Therefore, attempts to save the dying seedlings should concentrate on stimulating growth of new roots. In the experiments conducted by the Yixing May 7 Agricultural University, 300 to 500 parts to one of Dexon mixed with the acidic chemical fertilizer ammonium sulphate were used in time to prevent seedlings from further dying and to stimulate the seedlings already having rotting roots to grow new roots and revive growth.

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CHATER 3. TILLERING OF THE PADDY RICE PLANT

When the paddy rice's leaf age reaches 4 to 5 leaves, tillering begins. The tillering stage determines the number of panicles per mu and the number of panicles constitutes the basis of yield. Thus, understanding the physiological process of tillering and factors that affect tillering so that tillering and the formation of panicles from tillers can be stimulated is an important aspect in achieving high yields of paddy rice.

I. The Function of Tillering in Increasing Yield

Tillering is a characteristic formation of branching in the process of growth and development of paddy rice and is a manifestation of normal growth of the paddy rice plant. The development of the colony is based on the normal growth of the individual plant. If tillering does not occur in a field, this is an indication that the growth and development of the individual plant is obviously hampered and high yields will be very difficult to achieve. Survey results obtained by the Agricultural Technique Station of the Huishangang Area in Taojiang County, Hunan Province, show that a main panicle is superior to a tiller panicle, a lower tiller panicle is superior to a higher tiller panicle, a main panicle possessing tillers is superior to one not possessing tillers, a main panicle having two tillers is superior to a main panicle with only one tiller and a main panicle with three tillers is superior to a main panicle with two tillers (See Table 20).

Analysis of the above information provides a preliminary explanation of the fact that tillering is a good foundation for development of the plant colony and emergence of tillers serves a definite function in furthering the healthy growth of the individual plant. Healthy and strong plants that tiller normally have a well developed root system. The area for absorption of nutrients by the root system is expanded. This in turn furthers healthy growth of the part of the plant above ground. Even if the tillers die, plants having such tillers will have already formed a prosperous root system during the growth process and thus can continue to provide its main stem and large tillers with nutrients. Therefore, plants that have tillered are visibly better than plants that have not tillered. In addition, the survey conducted by the Agricultural Technique Propagation Station of Fengxian County of Shanghai Municipality obtained similar results (Table 21). Given conditions where the density in the paddy rice field is not too dense. All single plants with tillers or effective tillers grow strongly and healthily and produce large panicles and plenty of grains.

Table 20. Fruiting of Tiller Panicles and Main Stem Panicles of "Xiangaizao No. 8"

穗数情况 (1)	主茎穗及分蘖穗 (2)	穗长 (厘米) (3)	每穗粒数 (4)	每穗实粒数 (5)	空秕率 (%) (6)	千粒重 (克) (7)
(8) 主穗带一个蘖穗	主 (9) 穗	18.28	77.10	62.68	27.94	27.0
	分蘖穗 (10)	16.87	45.33	34.33	64.06	22.3
	平 (11) 均	17.54	61.67	49.11		
(15) 主穗带二个蘖穗	主 (9) 穗	18.41	79.84	67.00	22.16	27.3
	第一分蘖穗 (12)	17.00	67.10	48.64	44.60	25.1
	第二分蘖穗 (13)	16.62	44.62	33.67	79.38	22.0
	平 (11) 均	17.01	63.78	46.43		
(16) 主穗带三个蘖穗	主 (9) 穗	19.37	69.33	74.67	14.90	27.6
	第一分蘖穗 (12)	18.17	64.00	61.67	31.27	26.0
	第二分蘖穗 (13)	17.60	59.33	40.67	45.46	24.8
	第三分蘖穗 (14)	16.60	58.53	36.67		21.8
	平 (11) 均	17.89	66.35	48.63		

Remark: Planting hole and row distance is 4 x 5.2 cun

Key:
(1) panicle with tillers
(2) main stem panicle or tiller panicle
(3) panicle length (cm)
(4) number of grains per panicle
(5) number of filled grains per panicle
(6) Percentage of empty and semi-filled grains (%)
(7) 1000 grain weight (gram)
(8) main panicle with one tiller panicle
(9) main panicle
(10) tiller panicle
(11) average
(12) 1st tiller panicle
(13) 2nd tiller panicle
(14) 3rd tiller panicle
(15) main panicle with two tiller panicles
(16) main panicle with 3 tiller panicles

Practice shows that when the plants are planted reasonably, a certain proportion of tiller panicles must be established by stimulating early tillering and plentiful tillering. However, an overly abundance of tillers is not necessarily better, especially on double season rice plants. If the ratio of tiller

panicles in one field is too high because some tillers have "rushed forward," the plants often yield one to two more leaves than those simultaneously extending from the main stem. For example, when the main stem has 13 leaves, then according to the pattern of tillering, heading should occur when 5 leaves have emerged simultaneously with emergence of the 9/0 period. In actuality, heading often occurs after 6 to 7 leaves have emerged, causing heading, fruiting and maturation of the colony to occur nonuniformly. This is not beneficial to achieving large area high yields. Thus, transplanting of the single plant is used only in seed plants for rapid reproduction of seeds and for removing impure and poor quality plants or seeds and is not used in the large fields for production purposes. When there are too many tillers and when the colony over 'evelops, the field is seriously affected by dense growth. Both aeration and light permeability become very poor. The leaves on the lower part often wither early and the root system develops poorly, causing lodging and damage by disease and insects and hindering achievement of high yields. Thus, to achieve high yields, early and plentiful tillering sh should be stimulated but in a unit area the number of tiller panicles must be kept at a definite proportion, not too few and not too many.

Table 21. Fruiting of Tiller Panicles and Main Panicles of Early Rice

Tillering Conditions	Number of fields surveyed	Number of grains per panicle	Number of full grains per panicle	Empty and semi-filled grains (%)
Main panicles with no tillers	51	53.24	46.12	15.44
Main panicles with tillers	51	69.14	63.16	8.65
Tiller panicles	51	47.85	40.07	16.26

However, practice in production indicates that whether a field with plenty of tiller panicles can produce an increased yield depends on the function of the tiller panicles in the formation of the yield. Surveys conducted by concerned units show that it is difficult for double season rice which has a shorter tillering period to produce more panicles from tillers when the basic number of sprouts are insufficient because this will mean an insufficient number of effective panicles which in turn causes a reduced yield. Conversely, 100,000 basic sprouts of intermediate and late rice having a longer tillering period planted in one mu under highly fertile and well managed conditions can yield 250,000 to 300,000 large panicles (Table 22).

It can be seen from the table below that for single season late rice which has a longer tillering period, massive increases in the number of basic seedlings, suppression of tillering and raising the proportion of main stem panicles in the colony will not make the main panicles superior. Conversely,

(1) (万/亩)	(2) (万/亩)	(%) (3)	(4)	(5) (斤/亩)	(6)
29.8	26.0	100	68.7	811	1
22.1	25.0	98.6	66.3	820	6
16.8	26.9	67.8	71.6	817	7
18.1	26.5	68.6	73.3	863	8

Table 22. Relationship Between Basic Number of Seedlings and Number of Panicles of Single Season Late Rice

Key:
(1) basic number of seedlings (10,000/mu)
(2) number of panicles (10,000/mu)
(3) Percentage of main panicles (%)
(4) Number of full grains per panicle
(5) Yield (jin/mu)
(6) Number of fields

appropriate reduction of the basic number of seedlings and raising the percentage of the formation of panicles from tillers so that the tiller panicles can become part of the yield will visibly increase the number of panicles in the colony and more importantly will effectively improve the characteristics of the panicle, ease the conflict between the number of panicles and the number of grains and benefit the formation of high yields. Thus, in general, determination of the most reasonable proportion of tiller panicles should be coupled with consideration of the different types of paddy rice and levels of production. Intermediate and late rice have longer tillering periods. Thus the proportion of tiller panicles can be increased so that increased production can mainly rely upon formation of panicles from tillers. Double season rice has a short tillering period. Formation of panicles depends mainly on the main stem. Stimulating part of the tillers to form panicles will be advantageous to increasing production.

Hybrid rice has a strong tillering ability. During the seed bed stage, hybrid rice manifests early tillering and the tillers develop rapidly. In general, tillering begins at the third leaf period. Two tillers emerge during the fourth leaf period. Five or more tillers will have emerged by the seventh leaf period. After transplanting, most of the tillers which have emerged during the period in the seed bed will not die out. This is the reason why hybrid rice can depend upon the tillers which have emerged during the seed bed period to form panicles and produce large panicles and plenty of grains and achieve high yields. A survey conducted by the Agricultural Bureau of Nan County in Hunan Province (1977) shows that transplanted seedlings with tillers will achieve uniform heading earlier in the large field than transplanted seedlings not having any tillers. The percentage of formation of panicles from tillers is high. This is favorable to increasing the yield (Table 23). Hybrid rice seedlings also tiller early and the tillers develop

rapidly after transplanting. A survey conducted by the Huating Superior Variety Farm of Jiading County of the Shanghai Municipality (1977) shows the beginning of tillering in hybrid rice occurred earlier than that of the compared variety by 4 days. During the peak tillering period, the single hybrid rice plant had 5 to 6 more tillers than the compared variety (Table 24).

Table 23. Relationship Between Yield and Tillered Seedlings

(1)	(2)	(3)	(11)	(4)	(5)	(6)	(7)	(8)
(9)	1	9/19	7.3	[illegible]	34.3	27.1	808	
(10) 1	2	9/18	9.0	142.0	30.6	27.5	845	3.3
2	3	9/16	6.6	120.0	25.7	27.5	976	19.5
3	4	9/16	9.3	113.0	20.0	27.6	1082	28.0
4	5	9/15	10.2	110.0	21.6	27.6	1086	33.0

Key: (1) quality of seedling
(2) number of seedlings per hole
(3) full heading time (month/day)
(4) Number of filled grains per panicle
(5) percentage of empty grains (%)
(6) 1000 grain weight (gram)
(7) yield per mu (jin)
(8) increase in yield (%)
(9) seedlings with no tillers
(10) seedlings with __ tiller(s)
(11) number of panicle per hole

Table 24. Comparison of the Tillering Ability of Hybrid Rice and Ordinary Rice

(1)	(2)	(3)	(4)	(5)	(6)
(7) 南优2号	4/4	5/20	5.45	33.3	6.4
IR-24	"	"	11.67	44.5	3.1
南优3号	"	"	5.15	33.6	6.6
IR-661	"	"	11.04	40.9	3.4
南优6号	"	"	5.48	33.7	5.5
IR-26	"	"	12.24	46.2	3.6

Remark: Hybrid Rice: Nanyou No 2, Nanyou No 3 and Nanyou No 6.
Restorer Line: IR-24, IR-661, IR-26

Key: (1) Variety
(2) sowing time (month/day)
(3) transplanting time (month/day)
(4) basic number of seedlings (10,000/mu)
(5) number of tillers on the main stem at peak tillering period (10,000/mu)
(6) number of tillers of single plant
(7) Nanyou No __, IR-__.

II. The Tillering Process

A. Tillers and Their Description

The embryo of the ripe paddy rice seed already contains the differentiated tillering primordium of the node of the incomplete leaf and of the first leaf. As the plant grows, the tillering primordium differentiates from the base beside the leaf primordium and undergoes a series of differentiations to form the tillering bud (Diagram 24). Tillering of the paddy rice plant originates under proper conditions from the tillering bud (also called axil bud) inside the leaf axil.

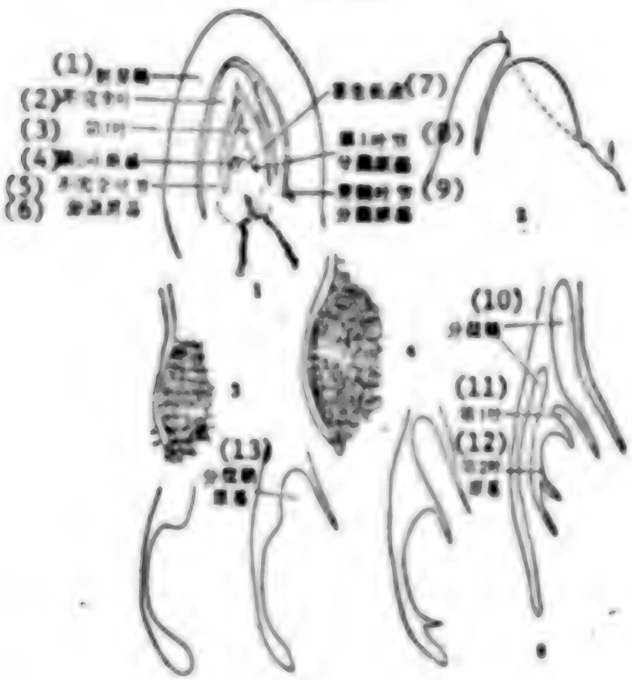


Diagram 24. Differentiation of the Tillering Bud of Paddy Rice
(Hoshigawa Kiyoshin (2502 1557 3237 6024)) (1975)

1. Tillering primordia in the embryo.
2. Differentiated tillering primordium at the base beside the leaf primordium (↓):
3-7. Process of differentiation of tillering primordium to tillering bud
8. Vertical cross section of a tillering bud.

Key:
(1) plumule sheath
(2) incomplete leaf
(3) first leaf
(4) second leaf primordium
(5) tillering primordium of the incomplete leaf node
(6) primordium of tillering sheath
(7) apical point of the stem
(8) tillering primordium of the first leaf node
(9) tillering primordium of the plumule leaf node
(10) tillering sheath
(11) first leaf
(12) primordium of the second leaf

The main stem of the paddy rice plant usually has 11 to 18 nodes. The stem of early rice varieties has between 11 and 13 nodes and the stem of the late rice varieties has between 16 and 18 nodes. Except for the uppermost node, one leaf grows from each of the remaining nodes. Each of the leaf's axil has one tillering bud. When the main stem reaches the fourth leaf period, the first tiller emerges from the axil of the leaf. As the number of leaves on the main stem increases, new tillers continue to emerge. At the same time, when each tiller produces its third leaf, the tillering plumule sheath tiller emerges. Tillers growing from the main stem are called first class tillers. Tillers growing from the first class tillers are called second class tillers. Tillers growing from the second class tillers are called third class tillers, and so on (Table 25).

a	4/0	5/0	6/0	7/0	8/0	9/0	10/0	11/0	12/0	13/0	14/0
b	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1
		1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2	9/2	10/2
			1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3
				1/4	2/4	3/4	4/4	5/4	6/4	7/4	8/4
					1/5	2/5	3/5	4/5	5/5	6/5	7/5
						1/6	2/6	3/6	4/6	5/6	6/6
							1/7	2/7	3/7	4/7	5/7
								1/8	2/8	3/8	4/8
c			1/1-0	2/1-0	3/1-0	4/1-0	5/1-0	6/1-0	7/1-0	8/1-0	1-0
d				1/1-1	2/1-1	3/1-1	4/1-1	5/1-1	6/1-1	7/1-1	1-1
					1/1-2	2/1-2	3/1-2	4/1-2	5/1-2	6/1-2	1-2
						1/1-3	2/1-3	3/1-3	4/1-3	5/1-3	1-3
							1/1-4	2/1-4	3/1-4	4/1-4	1-4
								1/1-5	2/1-5	3/1-5	1-5

Table 25. Correspondence between Leafing on the Main Stem and Leafing on Tillers of Paddy Rice

Explanation:
1. The main stem is represented by 0 as denominator, the number of the leaf is represented by the quotient. For example, 4/0 means the fourth leaf on the main stem.
2. Tillers growing from the main stem are first class tillers. The tiller growing from the axil of the first leaf on the steam is the No 1 tiller, expressed by the Arabic numeral, thus 1/1, and so on.
3. Tillers growing from the first class tillers are called second class tillers. Tillers growing from the tiller sheath node are represented by 1/1-0, and so on. Tiller growing from the axil of the first leaf is designated 1/1-1, and so on.

Key:
- (a) main stem
- (b) first class tillers
- (c) tiller sheath tillers emerged from the tiller sheaths
- (d) second class tillers on the first class tillers

Table 25 lists only the correspondence between the eight first class tillers on one main stem and the six second class tillers. According to the pattern of tillering, a main stem having 14 leaves should have 54 tillers (8 first class tillers, 21 second class tillers, 20 third class tillers, and 5 fourth class tillers) each having 4 leaves or more at the time the 14th leaf of the main stem (14/0) emerges. In actual production, the number of tillers that emerge is less. This is because during the seed bed period, dense sowing and poor light and nutritional conditions cause the several nodes at the base of the stem to remain in a dormant state so that they do not tiller. Some tillers that have emerged on the seedling do not have their own independent root system to support them and cannot withstand damage when uprooted; therefore they die after transplanting. When the seedling is uprooted for transplanting, the tillering buds on the first to the fourth node are either dormant or have withered and died and generally cannot grow into tillers. After jointing, several nodes above ground also have tiller buds that are dormant and cannot grow into tillers. Thus, a main stem having 14 leaves after transplanting will produce first class tillers only from the axils of the fifth leaf to the ninth leaf (5/0-9/0). Tillers seldom emerge from the axils of the other leaves. Whether these few first class tillers will emerge also depends upon the external conditions at the time. If the conditions are unfavorable, some tillers may not emerge.

B. Growth of Tillers

The growth process of tillers can be divided into two stages. The first stage lasts from the period when the tiller has 3 leaves to the time before 3 to 4 roots emerge. This stage is called the "heterotrophic" stage. The tillering bud depends mainly on the nutrients received from the main stem for growth into tillers. Since the amount of nutrients is limited, the amount of nitrogen in the tillers is reduced (and so are the amounts of phosphorus and potassium). The weight of dry substances does not increase rapidly. Ishitsuka Kimei (4258 1046 0823 2494) (1958) observed the changes in nitrogen content and dry weight during the process of tillering of paddy rice listed in Table 26 and illustrated in Diagram 25.

Table 26. Changes in Nitrogen Content and Dry Weight in the Tillering Process of Paddy Rice

Sample taken Date (mo/da)	6/26	6/30	7/7	7/14	7/21	8/6
Dry weight (milligram)	0.6	12.1	59.4	158	508	1520
Nitrogen content (%)	5.28	4.68	3.54	2.69	3.33	1.90

When the tiller has three leaves, it enters into the "autotrophic" stage, the second stage of growth. It now obtains inorganic nutrients from its own root system which causes the nitrogen content to rise again. The strength of photosynthesis also increases and the weight of dry substances rapidly increases. The tiller can now live independently. Isotope tracing experiments show that the small tillers with 1 to 2 leaves receive large amounts of assimilated products from the main stem while large tillers with 3 or more leaves

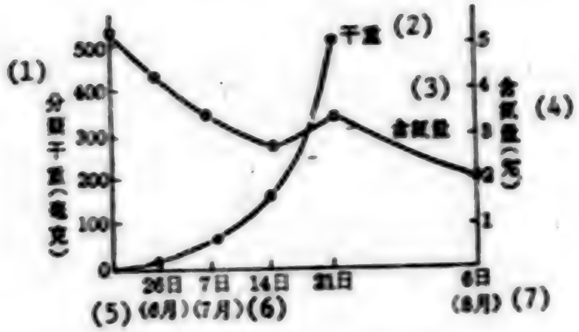


Diagram 25. Changes in Nitrogen Content and Dry Weight

Key: (1) dry weight of tillers (mg) (2) dry weight (3) nitrogen content (4) nitrogen content % (5) 26 June (6) July 7, 14, 21 (7) August 6

receive few assimilated products from the large stem. Thus all tillers that have three or more leaves prior to the jointing of the main stem have a good chance of becoming effective tillers.

C. Parallel Extension of Leaves and Tillers

Since the emergence of tillers depends upon the supply of nutrients manufactured by the leaves on the main stem, there is a definite relationship between the growth of tillers and leafing on the main stem. This relationship is called the simultaneous extension of leaves and tillers. When a leaf begins to grow, the tiller at the nodal position of the third leaf below it grows simultaneously. If the leaf is designated by "N", then the tiller at the (N-3) leaf position begins to emerge. For example, when the fifth leaf (5/0) emerges, the tiller bud at the second leaf position begins to tiller and grow (Diagram 26). The next class of tillers then emerge on the tiller in the same manner. Thus, when conditions are suitable, the emergence of a leaf on the main stem is accompanied by the simultaneous emergence of several tillers. These tillers are called the simultaneous tillers of that leaf on the main stem.

For example, when the 9th leaf (9/0) emerges, a first class tiller emerges from the node at the position of the sixth leaf and a second class tiller emerges on the node at the position of the third leaf. Since these two tillers appear simultaneously, they share simultaneous extension as tillers.

What is the reason for the difference of three leaf nodes during the emergence of tillers? It is because when a leaf on a node of the main stem begins to emerge and extend, the tillering bud of this new leaf begins to differentiate while the tillering bud on the leaf position below it has basically completed

its differentiation and the tillering bud on the next leaf position below that has already begun to grow and is extending within the leaf sheath. The tillering bud on the third leaf position below has already emerged from the lea sheath to become a tiller. Thus the nodal position of an emerging first class tiller and the nodal position of the newly emerging leaf on the stem are exactly three leaf nodes apart. Therefore, according to the positions of the newly emerged leaves on the main stem, the time of tillering and the position of tillering can be estimated and taken as indicators to predict whether tillering will be effective and the size of the tiller panicles.

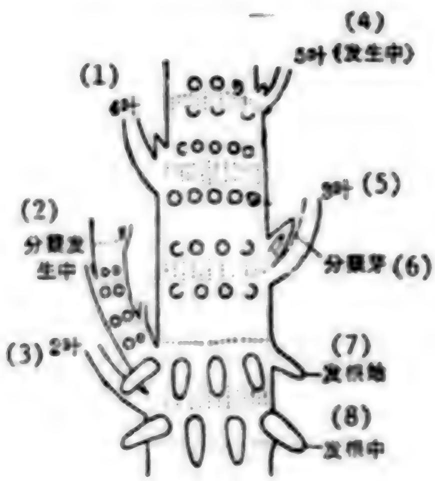


Diagram 26. Diagram of the simultaneous extension of a tiller emerging at the (N-3) leaf node position and the Nth leaf (Hoshigawa Kiyoshin, 1975)

Key:
(1) 4th leaf
(2) tiller is emerging
(3) 2nd leaf
(4) 5th leaf (emerging
(5) 3rd leaf
(6) tillering bud
(7) rooting begins
(8) rooting in progress

Simultaneous extension of a leaf and a tiller and the simultaneous extension of tillers are both internal patterns of tillering. But tillering according to this pattern is closely related to the external conditions of light, water and planting density. When a certain tiller emerges and the environmental conditions are not appropriate, the tillering bud at this nodal position will not develop but will remain dormant. Even if the conditions become suitable later on, this tillering bud will not produce ti-lers. This is expressed by the common expression that "nobody will wait any longer if you are late." Thus, in production, timing and timely stimulation are important.

Experiments also show that because the vegetative area of the transplanted single plant is large, tillering is plentiful. For example, the transplanted single plant produces 11 more tillers than any of the 6 seedlings planted in

one hole (Diagram 27). The earlier tillering occurs the greater the possibility the tillers will form panicles Formation of panicles also varies according to different vegetative areas of the seedling in the field. If a transplanted single plant has 15 leaves on its main stem, most of the tillers emerging simultaneously with the 11th leaf (11/0) will form panicles. On the seedlings transplanted in multiples and having 14 leaves, one leaf less than the transplanted single plant, tillers emerging simultaneously with the 10th leaf (10/0) may not necessarily become panicles. The transplanted single plant tillers early and the duration of the tillering period lasts for a long time. Thus, whether tillers emerge and become panicles is greatly affected by external conditions.

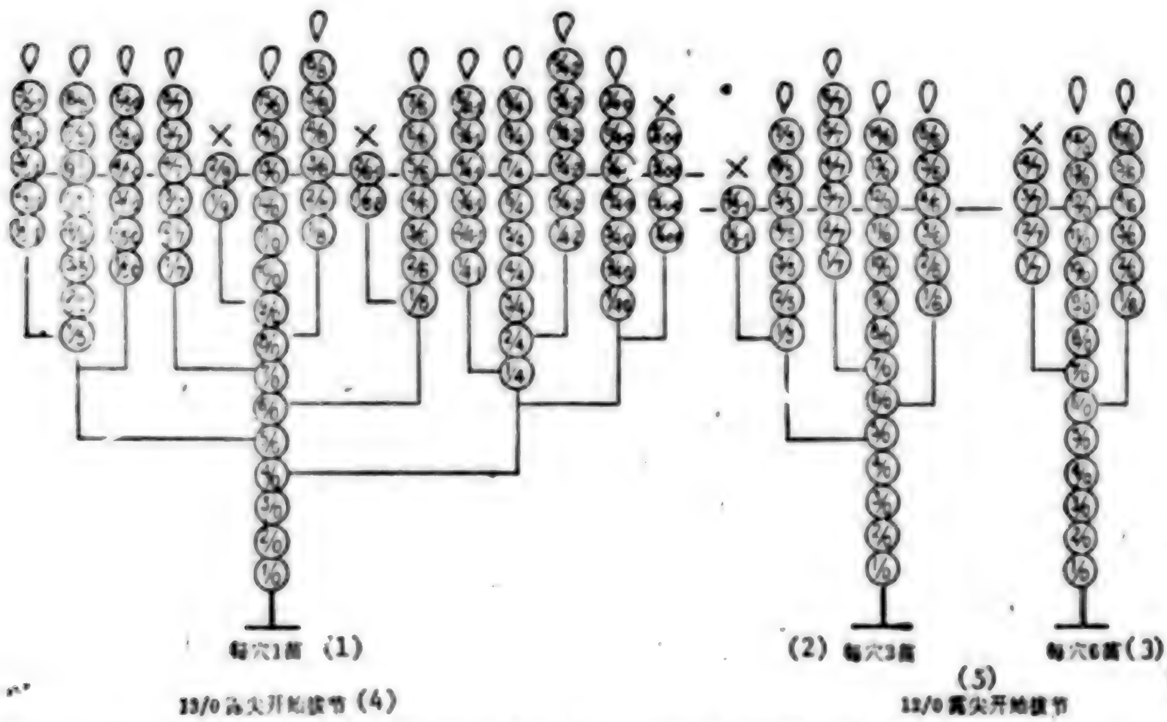


Diagram 27. Relationship between the different number of seedlings per hole and tillering (Jiangsu Agricultural College, 1972) (x indicates tillers which have not yet formed panicles; test variety is Yangxuan 14)

Key: (1) one seedling per hole
(2) 3 seedlings per hole
(3) 6 seedlings per hole
(4) 13/0 shows tip and begins to joint
(5) 12/0 shows tip and begins to joint

III. Transportation of Substances Between Tillers and the Main Stem

Tillers grow from the main stem. Emergence of tillers depends upon the sufficient supply of nutrients provided by the stem. Under ordinary conditions, the photosynthetic products produced by the leaves on the main stem are mostly supplied to the main stem's own roots, stems and leaves for their growth. About 35.43 percent of the nutrients are transported to the small, young tillers for

their growth. If the photosynthesis by the leaves is suppressed and photosynthetic products are insufficient, the organic nutrients manufactured in the leaves of the main stem will not be transported to the tillers. As the main stem begins to extend and young panicles begin to differentiate, the need for photosynthetic products by the main stem itself increases gradually leaving no extra photosynthetic products for the tillers. Thus when the growth of the main stem enters the young panicle differentiation stage, a very small amount of photosynthetic products will flow to the tillers. Ma Shouxiang (7456 1108 4382) (1964) determined that the amount of photosynthetic products during the heading stage that flows to the tillers constitutes only 3.8 percent during the milking ripe stage it constitutes only 2.5 percent (Diagram 28).

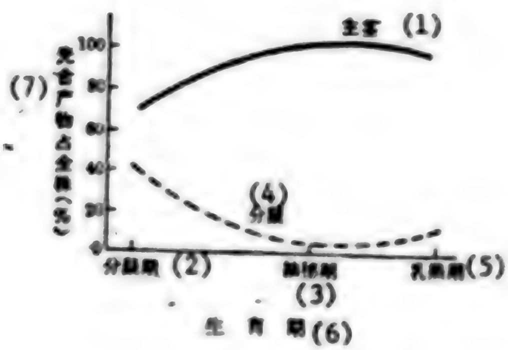


Diagram 28. Distribution of Photosynthetic Products Produced by the Leaves on the Main Stem During the Various Growth Stages of Paddy Rice

Key:

(1)	main stem	(5)	milky ripe stage
(2)	tillering stage	(6)	growth period
(3)	heading stage	(7)	products of photosynthesis as percentage of entire plant
(4)	tiller		

The single tiller depends on the supply of nutrients from the main stem for its growth when it is young. When it acquires three leaves it begins to grow roots and also acquires a large leaf surface area. These enable the tiller to gradually make the transition to independence. Tanaka (1957) used C^{14} isotope tracers to determine transportation of photosynthetic products manufactured in the leaf of the main stem that is the center of activity to the tillers at the various leaf positions. The results are shown in Table 27.

Table 27 shows that the C^{14} entering leaf 5/0 was mostly transported to the three leaves 6/0, 2/2 and 1/3. At this time, 6/0 was just extending and 6/0, 2/2 and 1/3 leaves were all simultaneously extending leaves. Ordinary synthetic products were transported mostly to these three extending leaves with only one exception, the leaf 3/1. This showed that the extension of leaf 3/1 depended mainly on 1/1 and 2/1 for the supply of photosynthetic

Table 27. Distribution of C^{14} Assimilated by the 5/0 Leaf

(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
6/0	6812	3/1	186	2/2	2442	1/3	2918
5/0	28300	2/1	146	1/2	328		
4/0	630	1/1	63				
3/0	316						
2/0	90						
1/0	21						

Key: (1) name of leaf
(2) pulse

products. The supply of photosynthetic products by the main leaf was now of secondary importance. Only those tillers having 2 leaves were still being supplied with the needed photosynthetic products by the main stem and were still in the heterotrophic stage.

Ma Shouxiang (7456 1108 4382) (1964) studied whether the photosynthetic products manufactured by the tiller leaves were being transported to the main stem. The study indicated th a small part of photosynthetic products manufactured by the tiller leaves during the tillering period (1..96 percent) flowed into the main stem. Later, as the tiller entered into the young panicle differentiation stage during extension of the stem, no extra photosynthetic products were being transported to the main stem. During the heading period, only 3.65 percent of the photosynthetic products manufactured by the tiller leaves flowed back to the main stem. The situation changed entirely after the milky ripe stage. The tillers not only maintained their independence in the supply of nutrients, but also transported about one third (38.18 percent) of the photosynthetic products back to the main stem. Between 25.5 percent and 36.1 percent of the photosynthetic products of ineffective tillers were being transported to effective tillers. Thus, it cannot be denied that tillering serves an active function in the formation of panicles and grains. The transportation of photosynthetic products between the main stem and the tillers are both mutually independent and connected (Diagram 29).

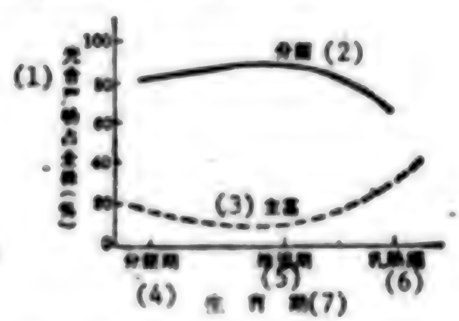


Diagram 29. Distribution of Photosynthetic Products of Tiller Leaves during the Various Stages of Growth of Paddy Rice

Key: (1) photosynthetic products as part of the entire plant (%)
(2) tiller
(3) main stem
(4) tillering stage
(5) heading stage
(6) milky ripe stage
(7) growth periods

In addition, the exchange between tillers and the main stem of inorganic nutrients absorbed by the root system when the tillers are still young indicates that the inorganic nutrients needed by the tillers still depend upon the supply provided by the root system of the main stem. When the tiller reaches the third leaf stage, the tiller acquires its own root system to absorb inorganic nutrients, begins to live independently and does not need the main stem to supply it with inorganic nutrients. But, during the tillering stage, more inorganic nutrients are being transported between the tiller and the main stem, whether the inorganic nutrients are absorbed by the root system of the main stem or the root system of the tiller. The inorganic nutrients absorbed by either root system can be supplied to the tiller or the main stem for use. Of the total amount of inorganic nutrients transported to the part of the plant above ground, the portion supplied by the root system of the main stem constitutes a very large proportion. The inorganic nutrients absorbed by the root system of the main stem not only actively enter the main stem but more are also transported to the old tillers than to the new tillers. This can be proven by the experiment conducted by Ishitsuka Kimei (4258 1046 0823 2494) (1958) in which isotope P^{32} (Phosphorus^{32}) was fed to the main stem to observe how much was received by the tillers (Table 28).

Table 28. Distribution of P^{32} Absorbed by the Roots of the Main Stem in the Tillers

(1) 器官	(2) P^{32} 含量 (%)
主茎 (3)	50.2
7叶分蘖 (4)	19.9
6叶分蘖 (5)	13.8
5叶分蘖 (6)	8.6
4叶分蘖 (7)	7.6

Key:
(1) organ
(2) content of P^{32} %
(3) main stem
(4) 7th leaf tiller
(5) 6th leaf tiller
(6) 5th leaf tiller
(7) 4th leaf tiller

During the heading and milky ripe stages, the exchange of inorganic nutrients absorbed by the root systems of the main stem and of the tillers is minimal. The tiller and the main stem are basically independent.

In summary, it can be seen in the exchange of materials between the main stem and the tiller that the tiller serves as the regulator of nutrients in the paddy rice plant. Emergence of tillers does not weaken the growth of the main stem. Tillering is a manifestation of a healthy and strong plant.

IV. Causes That Affect Tillering

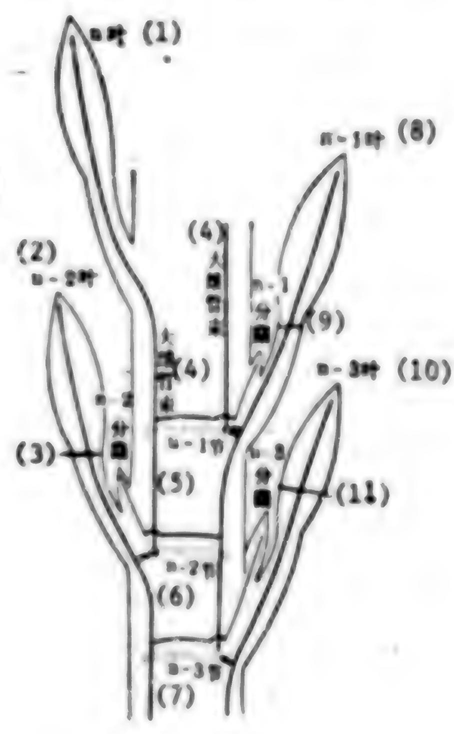
The amount and time of tillering is related not only to the variety's tillering characteristics but also affected by internal factors and external conditions. These are explained in the following:

A. Inner Causes That Affect Tillering

The nutrients needed at the beginning of tillering are all supplied by the main stem and transported via the system of vascular bundles. The number and the thickness of the vascular bundles depend upon the thinness and thickness of the seedling. The strong seedling's tiller buds contain numerous and thick vascular bundles which facilitate the transportation of nutrients. Therefore how the vascular bundles are connected in the body of the plant directly affects the nutritional source for tillering. Studies indicate the vascular bundle trunk of the nth leaf enters the nth node and extends downward towards the n-1 node where it connects with the vascular bundle trunk of the n-1 tiller bud. Then it extends to the n-2 node where it breaks up and branches out. Most of the branched out parts enter the stem node of the n-2 leaf and connect with the vascular bundle trunk there. Finally when the vascular bundle trunk enters the n-3 node, it reconnects with the vascular bundle trunk of the n-3 tiller bud (Diagram 30). This is to say, the transport tissues inside the body of the plant connect most completely at the nth leave, n-1 tiller, n-2 leaf, n-3 tiller,... Thus when the nth leaf and n-3 tiller's first leaf extends simultaneously, the nutrients are mainly supplied by the n-2 leaf. This is also proved by Ishitsuka Kimei (4258 1046 0823) (1958) in his experiment using isotope P^{32} to feed the 7/0 leaf (Table 29).

Diagram 30. The Transport System of the Vascular Bundles in the Paddy Rice Plant (From the "Rice Planting Principles and Techniques" of the Jiangsu Agricultural College [Nong Xueyuan] 1977)

Key: (1) nth leaf
(2) n-2 leaf
(3) n-2 tiller
(4) Vascular bundle trunk
(5) n-1 node
(6) n-2 node
(7) n-3 node
(8) n-1 leaf
(9) n-1 tiller
(10) n-3 leaf
(11) n-3 tiller



Remark: The dark lines in the diagram indicate the vascular bundle; the dotted lines indicate small vascular bundle trunks.

Table 29. Distribution of P^{32} absorbed by 7/0 leaf

Leaf position	Pulse	Tillering	Pulse
10/0	80		
9/0	104		
8/0	51		
7/0	355	7 tiller	27
6/0	12	6 tiller	77
5/0	9	5 tiller	38
4/0	3	4 tiller	36

Table 29 shows that the most amount of P^{32} absorbed by the 7/0 leaf was transported via the main stem to the 9/0 leaf. Of the tillers, the most amount was transported to the 6th tiller. This shows that the nutrients for the tillering of the 6th tiller come mainly from the 7/0 leaf. The n-3 leaf protects the n-3 tiller and provides the nutrients needed for rooting from the n-3 leaf node. This is also the internal reason for the difference of three leaf nodes between tillering and leafing from the main stem and also the reason why each tillering requires four green leaves. For example, when the 6th tiller on the main stem begins to tiller, there should be four green leaves 9/0, 8/0, 7/0, and 6/0. In this way, the 6/0 leaf serves to protect the 6th tiller, the 7/0 leaf provides the nutrients for growth of leaf 9/0 and the 6th tiller. If there are less than 4 or more green leaves, tillering generally will not occur.

B. External Conditions That Affect Tillering

The external conditions that affect tillering are more complex. They can be divided into the following major aspects:

1. Temperature

Isothermal experiments show the most suitable temperature for tillering is between 28°C and 31°C. When the temperature crops below 24°C or rises above 37°C, tillering will be adversely affected. Tillering ceases when the temperature drops below 18°C. However, the daily average temperature is different from the isothermal temperature. It has been determined that during the effective tillering period, the temperature demands of tillering can be satisfied when the daily average temperature is above 22°C and the highest temperature is about 27°C.

Since the tillering nodes of the paddy rice plant are generally 0.8 cun to 1 cun below the surface of the soil, the soil temperature and water temperature affect tillering more. Studies indicate shallow irrigation during the tillering period of early rice (depth of water is between 1 and 2 centimeters) keeps the soil temperature at a depth of 4 centimeters during daytime at 1°C to 2°C higher than deep irrigation (depth of water is 5 centimeters). But during the night, the temperature of the soil irrigated shallowly is 0.5°C lower than the temperature of the soil irrigated deeply (Diagram 31). Observations indicate that under shallowly irrigated conditions and 11 days after transplanting (June 6), the single plant's tillering index reaches 1 whereas under deeply irrigated conditions, the index reaches only 0.7. Thus during the tillering period, shallow and frequent irrigation, especially shallow irrigation during the day and deep irrigation during the night, will help raise the temperature of the soil in the paddy rice field and stimulate tillering and growth. This is an effective measure to overcome occurrences of stunted seedlings and halting of tillering caused by low temperatures during the tillering period of early rice in the middle and lower reaches of the Chang Jiang region.

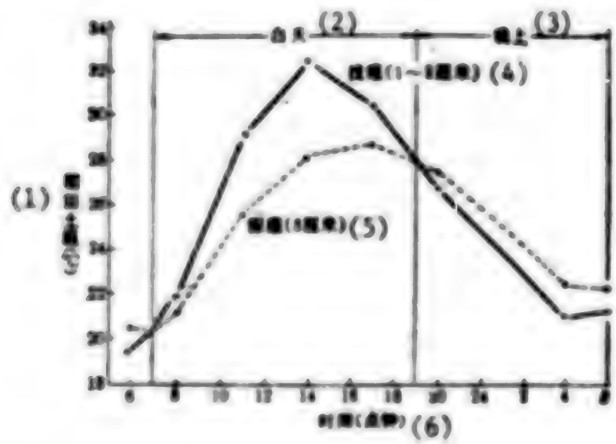


Diagram 31. Effect of Shallow Irrigation and Deep Irrigation upon Soil Temperature in the Rice Field During Paddy Rice's Tillering Period (Shanghai Municipal Weather Bureau, 1974)

Key: (1) soil temperature in the rice field °C
(2) daytime
(3) night time
(4) shallow irrigation (1-2 centimeters)
(5) deep irrigation (5 centimeters)
(6) time (hours)

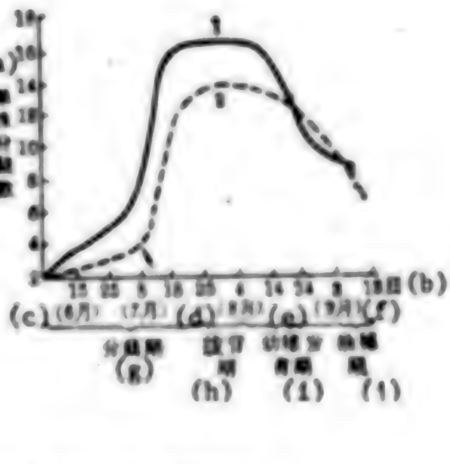
In addition, the depth of transplanting will also affect the soil temperature of the area surrounding the tillering nodes and thus affect tillering. It has been determined that the soil temperature of the paddy rice field at a depth of 2 cun is lower than that at a depth of 1 cun by 2°C. Under normal

conditions, the tillering node is 1.0 to 1.5 millimeters. At about 1 cun below the surface of the soil, the temperature is relatively high and aeration is good, which are advantageous to tillering. If the seedling is planted too deeply, the temperature surrounding the tiller node is low and aeration is poor. Under this condition, the paddy rice plant will have to force the internode of the tiller nodes at the base of the plant to extend since these were not supposed to extend. This forms "two section roots" or "three section roots" so that the tiller nodes can be raised to about 1 cun under the surface of the soil where the temperature is higher and aeration is better. This abnormal formation of nodes requires between 5 and 7 days for every node so formed. Thus, the tillering time is delayed, nutrients are wasted, full utilization of nutrients by the healthy tillers at the low nodal positions is hindered and tillers cannot emerge. Since only 2 to 3 leaves are pushed upward by the rise of the nodal positions, those leaves that are not pushed upward rapidly wilt and die. Since tillering can occur only when there are green leaves and only from nodes with at least 4 or more green leaves, this greatly delays the tillering period and reduces effective tillers. Even those tillers which do become effective tillers will produce small panicles which mature nonuniformly because of the delay in tillering and the greater distance from the main stem.

2. Moisture

The tillering stage is a period in which the paddy rice plant is sensitive to moisture. The former Chinese Academy of Agricultural Sciences' Jiangsu Branch Academy (1957) showed by experiment that the degree of dampness of the soil layer surrounding the tiller nodes directly affects tillering. If the water layer of the soil is drained, tillering is visibly suppressed (Diagram 32). Thus, to assure formation of a sufficient number of panicles, the field should not be drained during the tillering period but should be irrigated shallowly to satisfy the demands of tillers for moisture, temperature and air. When the soil contains more reduced substances that hinder the normal growth and development of paddy rice (at this time the field is often mushy and air bubbles emerge from the soil), the field must first be drained, lightly held for aeration to raise permeability of the soil and then irrigated shallowly and frequently.

Diagram 32. Effect of Moisture Conditions of the Soil Upon Tillering of Paddy Rice during the Tillering Period (Variety: "353") 1. Water level; 2. drying the field during tillering period ↑ time of re-irrigation



Key: (a) number of tillers of single plant
(b) date
(c) June
(d) July
(e) August
(f) September
(g) tillering period
(h) jointing stage
(i) young panicle development period (j) heading period

3. Light

The paddy rice seedling's organic nutrients come from photosynthesis. A necessary condition for photosynthesis is light. If there are many damp rainy days and the amount of light is insufficient, then there will be few assimilated products. The leaves and the leaf sheath will grow fast but the seedling will be small and thin which are unfavorable conditions for tillering. Even if tillers emerge they will wilt and die because of insufficient nutrients. Conversely, when there are many sunny days and strong light, the leaf sheaths will be short, the plant will be strong and healthy, and tillers will emerge plentifully and rapidly. The former Chinese Academy of Agricultural Sciences' Agrometeorological Laboratory determined that the intensity of light affects tillering greatly. When the intensity of light is reduced to 5 percent of the intensity of natural light, tillers do not emerge and even the main stem may die (Table 30).

Table 30. Effect of Strong Light on Tillering

(c) (a) / (d)	(b) 5%	(b) 25%	(b) 50%	(b)
6/16	—	—	—	1.10
6/20	—	—	—	1.37
6/24	—	—	1.05	1.67
6/28	0.91	1.04	1.48	2.44
7/2	0.80	1.07	1.88	2.91
7/6	—	1.19	2.16	3.39
7/10	0.84	1.24	2.30	3.83
7/13	0.79	1.26	2.30	4.09

Note: (1) The number of tillers of the single plant includes those on the main stem. Since the intensity of light is only 5 percent of that of natural light, some seedlings have died and thus the number of tillers is less than 1.

(2) Tested variety was "Shuiyuan 300 grain," planted in pots on June 2 and subjected to testing on June 13.

Key: (a) treatment
(b) intensity of natural light
(c) number of tillers per plant
(d) (month/day)

Under ordinary conditions the intensity of light is sufficient to satisfy the requirement of the paddy rice plant during tillering (the light saturation point during paddy rice's tillering period is 50,000 meter-candles. The

intensity of light on sunny days is 100,000 meter-candles or more and the intensity of light on cloudy days is between 10,000 and 20,000 meter-candles). If transplanted too densely, few tillers will emerge and many will die because of insufficient light. [For example,] during transplanting, if too many seedlings are planted in one hole, such as 10 or more young plants in one hole, overly dense growth from that hole will become serious and the seedling at the center will die from suffocation. Thus when transplanting, the density of the seedlings must be reasonable in order to maintain a good light condition among the plants so as to facilitate tillering.

4. Inorganic Nutrients

Inorganic nutrients greatly affect tillering of the paddy rice plant and especially great is the effect on nitrogen on tillering. Since the initial development and beginning period of growth of the tiller bud depend upon the nutrients from the main stem, the nutritional content of the plant also affects tillering. Studies show when the leaves contain 5 percent nitrogen, 0.2 percent phosphorus and 1.5 percent potassium, tillering will be fast. When the nitrogen content of the leaves is less than 2 percent, the content of phosphorus is less than 0.03 percent and the content of potassium is less than 0.5 percent, tillering reduces or ceases. The former Plant Physiology Institute of the Chinese Academy of Sciences (1959) showed by experiment that the content of nitrogen in the leaves exerts a greater affect upon tillering (Diagram 33). When the content of nitrogen in the leaves is less than 1.5 percent, tillering (as a life function) ceases.

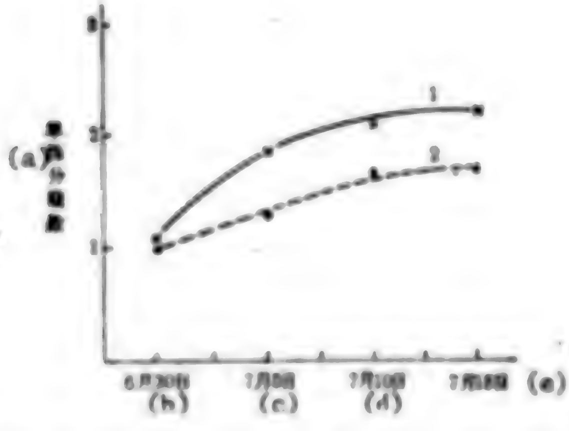


Diagram 33. Effect of the Content of Nitrogen in the Leaves Upon Tillering of the Paddy Rice

1. Nitrogen content of the leaves is 4.18 percent
2. Nitrogen content of the leaves is 3.05 percent Variety: "Laolaiqing"

Key: (a) number of tillers of the single plant
(b) June 30
(c) July 5
(d) July 10
(e) July 15

Because inorganic nutrients greatly affect tillering of paddy rice, fertility and the amount of fertilization are very closely related to tillering and formation of panicles in paddy rice. In fertile fields with plenty of fertilizers, tillers emerge early and abundantly and the tillering period is long. Conversely, in sterile fields with little fertilization, tillers emerge late, few tillers emerge and the tillering period is short. Especially for double season rice, tillering fertilizers greatly affect early and rapid tillering and "the initial burst of tillering activity" (Table 31). Fertilizers for tillering of double season rice are usually applied 4 to 5 days after transplanting. A mixture of about 40 jin of ammonium hydrocarbonate and 30 jin of calcium superphosphate is applied per mu (and the field is immediately weeded). Then 7 to 10 days afterwards, another 15 jin of ammonium hydrocarbonate per mu can be applied selectively (only where the growth trend is weak and where leaves appear yellow).

Table 31. Effect of Tiller Fertilizers Upon Tillering and Panicle Formation

(1) 基肥 (猪粪) (斤/亩)	(2) 分蘖肥 (硫酸铵, 斤/亩)		(3) 基本苗 (万/亩)	(4) 日平均分蘖势 (万/亩)			(5) 万穗/亩	(6) 其中分蘖穗 (%)	(7) 亩产 (斤/亩)
	(8) 分蘖始期	(9) 分蘖盛期		6/21~7/1	7/1~7/11	7/11~7/18			
2790	20.0	13.3	14.3	1.36	1.68	0.26	33.6	57.4	576
2790	—	—	14.1	0.69	1.16	0.02	24.5	42.4	575

Key: (1) Base manure (hog manure) (jin'mu)
(2) Tillering fertilizer (ammonium sulphate jin/mu)
(3) Basic number of seedlings (10,000/mu)
(4) Daily average tillering trend (10,000/mu)
(5) 10,000 panicles/mu
(6) Tiller panicles %
(7) Yield per mu (jin/mu)
(8) tiller beginning
(9) tiller peak

V. Effective Tillers and Ineffective Tillers

The speed of growth of the various tillers on the paddy rice plant is not the same. Within the same period, some tillers grow fast and some grow slowly. Even the same tiller may grow fast some times and slowly at other times. Prior to jointing, the speed of growth of small tillers is faster, as if trying to catch up with the main stem and the large tillers. After jointing, the larger tillers grow faster and faster while the growth of smaller tillers becomes slower and slower and may even cease. Some small tillers stop growing the day them emerge. Thus, tillering begins to polarize towards two extremes. The causes of this polarization are both internal and external.

It has been noted above that although the paddy rice plant can produce many tillers, not all tillers become panicles. In particular, double season rice which has a short tillering period has a very low percentage of panicle formation from tillers when grown in large fields. Generally about 30 percent on only 1.1 to 1.[illegible] panicles are formed on a single plant, very few plants have 2 panicles. All tillers that can head and fruit are called effective tillers. Those that cannot are called ineffective tillers. Thus to increase the number of effective panicles, emergence of tillers must be stimulated and the percentage of formation of panicles from tillers must be raised.

To differentiate between effective tillers and ineffective tillers and to stimulate ineffective tillers to transform themselves into effective tillers, the pattern of panicle formation from tillers and the relationship between the formation of panicles from tillers and external conditions must be studied.

A. Patterns of Formation of Panicles From Tillers

In general, the beginning period of tillering (before the three leaves period) depends upon the nutritional supply from the main stem. The tillers themselves do not possess the ability to grow independently. When environmental conditions are not favorable, the supply of nutrients by the main stem reduces and tillers may possibly die. When three leaves emerge on a tiller, the tiller beings to root and gradually advances towards independent survival. When the tiller possesses four leaves, it will have acquired a rather healthy root system and can survive independently without the nutritional supplies from the main stem.

Prior to jointing, the main stem and large tillers have more nutrients for transportation to the small tillers. After jointing, the stalk, panicles and leaves of the main stem and large tillers grow rapidly and require large amounts of nutrients and the supply of nutrients to small tillers sharply decreases. At this time, some of the tillers that cannot survive independently will cease to grow because of a deficiency of nutrients, later die. Thus, in production, the jointing period is often taken as the demarcation period between effective tillers and ineffective tillers or the critical period of formation of panicles from tillers. Thus, at the time the main stem joints, tillers with only 1 to 2 leaves generally will all become ineffective tillers. Tillers with 3 leaves already possess the possibility of becoming panicles. But whether tillers possessing 3 leaves become panicles will depend upon actual conditions. On the one hand tillering is greatly affected by the nutritional condition of the soil and the condition of light in the colony and on the other hand it is related to the condition of tillering (such as the condition of the development of the root system and the surface area of the leaves). In general, tillers with 4 leaves or more can all basically form panicles. The more leaves the stronger the tiller's ability to survive independently and the greater the possibility of forming panicles.

Furthermore, during the tillering period and according to the relationship of simultaneous extension of the leaves and tillers, every leaf on the main stem needs 5 to 6 days to grow. Thus, tillers must emerge 15 days prior to

jointing of the main stem so that when the main stem joints there will already be 3 leaves and the beginning of a definite independent root system for independent absorption and production of nutrients so that there is the possibility of forming panicles. In addition, the earlier tillers emerge, the more numerous the emergence of leaves at the time of jointing of the main stem, the more developed the root system will be, the stronger the ability for independent vegetative growth, the higher the percentage of formation of panicles and the larger the panicles will become.

B. External Conditions That Affect Formation of Panicles from Tillers

Demarcation of the effective tillering period and the ineffective tillering period is relative. The two periods change according to changes in light conditions and nutritional conditions occur. If there are too many tillers in the large field causing serious overly dense growth, the tillers at the bottom part of the plant will die because of a deficiency of light and poor photosynthetic conditions even though the tiller has 4 leaves. Conversely, if the growth of the colony in the large field is appropriate, light permeability is good, there is sufficient amount of light at the bottom part of the plant, and the amounts of fertilization and irrigation water do not lag behind, small tillers which only have 2 to 3 leaves may become panicles because of the assured sufficiency of nutrients. If the condition of light is poor, even tillers on the main stem sometimes do not form panicles. Thus, reasonable planting in production (including the number of holes per mu, the number of seedlings per hole, the direction of the rows and the distance among plants) and control of tillering (such as drying the field under the sun) at the time when the number of tillers in a mu reaches a definite number are important measures to assure that the development of individual plants will yield a definite percentage of tillers which become panicles which are large and plentiful. In addition, fertilization, especially the application of nitrogen fertilizers, serves an important function in stimulating the formation of panicles from tillers. Under conditions in which fertilizers are deficient, large tillers and even the main stem will die one after the other, resulting in a very low percentage of panicle formation from tillers. Conversely, if fertilizers and moisture are sufficient, small tillers not having 4 leaves at the time of jointing of the main stem will also be able to form panicles, and the percentage of panicle formation from tillers will be high. For example, when transplanting the single plant, tillers with 2 leaves at the time the main stem joints will mostly be able to become panicles. When the number of seedlings in a hole is small, tillers with only 2 leaves at the time when the main stem joints will also be able to form panicles.

The above shows that taking the jointing period as the demarcation period for ineffective tillering and effective tillering is relative. Effective tillers may transform into ineffective tillers and ineffective tillers may transform themselves into effective tillers under definite conditions. The key is to create conditions favorable to the transformation of tillers and to fully develop man's subjective initiative.

C. Formula for Calculating Formation of Panicles From Tillers

The emergence of effective tillers and ineffective tillers of paddy rice are not only differentiated by the period of jointing but can also be calculated by a simple formula. In the calculation, the total number of leaves during the entire life of the particle variety of rice, the number of extending internodes after jointing and the time of sowing and transplanting must be known. The method of calculation follows:

Effective tillering period = total number of leaves of the main stem - number of extending internodes.

For example, early rice variety "Erjiuqing" has a total of 11 leaves during its life and 4 extending internodes above ground. Then 11 - 4 = 7 means that for "Erjiuqing" the tillers emerging up to the time when the 7th leaf emerges are basically all effective tillers. Another example, early rice "Guangluai No 4" has 13 leaves throughout its lifetime and 4 extending nodes above ground. Thus 13 - 4 = 9 means that for "Guangluai No 4," the tillers emerging up to the time when the 9th leaf emerges are effective tillers. Thus, the early rice "Guangluai No 4" variety's effective tillering period has two more leafing cycles than the "Erjiuqing" variety. This formula is also suitable for calculating the tillering period of late season rice.

Then when is the period in which ineffective tillers emerge? The method of calculation is:

Ineffective tillering period = total number of leaves of the main stem - number of extending internodes + 2.

Tillers emerging at the time of emergence of this leaf and all those tillers emerging afterwards are ineffective. Again taking "Erjiuqing" as an example: 11 - 4 + 2 = 9. This means all tillers emerging simultaneously with the 9th leaf and all tillers emerging afterwards are ineffective tillers. The tillers that emerge in between, i.e., tillers emerging with the 8/0 leaf may become panicles or may not, depending on two conditions: the size of the colony and the level of fertilization. Where the colony size is small and the level of fertilization is high, the tillers emerging simultaneously with the 8/0 leaf will become panicles. On the other hand, if the size of the colony is large and the level of fertilization is low, the tillers emerging simultaneously with the 8/0 leaf will not be able to become panicles. The reason for this is mainly related to the pattern of growth and development of the tillers. Under ordinary conditions after tillering, the tillers with one or two leaves do not have roots and all the nutrients depend basically on the main stem for supply. After the main stem joints, there will not be any extra nutrients to supply the tillers. Thus, these tillers will not be able to become panicles. Tillers with 3 leaves at the time the main stem joints have just begun to root and are in transition towards independent survival but cannot yet survive. Tillers with 4 leaves or more leaves have their own root system and can survive independently without the supply of nutrients from the main stem. Thus, for

early rice "Erjiuqing," tillers that emerge with the 9/0 leaf and that possess 2 or less leaves at the time when the main stem joints will not form panicles. Only those tillers emerging simultaneously with the 8/0 leaf, possessing 2 leaves and one new leaf at the time the main stem joints and just reaching the third leaf period may or may not form panicles.

To produce a sufficient number of panicles in the field, the total number of tillers on all the stems in the entire field must be equal to the total number of panicles desired during the effective tillering period. For example, for the "Erjiuqing" variety, it is desirable to produce 400,000 effective tillers per mu. Thus, when the rice seedling reaches the 7th leaf period, the total number of tillers on all stems in the entire field should reach 400,000/mu. Conversely, if during the effective tillering period the sufficient number of tillers on all the stems has not been reached, then all measures should be taken to stimulate the intermediate types of tillers, i.e., those tillers that may or may not become panicles so that they will become effective tillers.

VI. Development of Tillers and Stems of a Colony of Plants in a High Yielding Rice Field

The appropriate rate of development of the colony in a high yielding field as determined by the experiments conducted in the Shanghai area for double season rice is a yield of 400,000 to 450,000 panicles per mu. This number is more suitable in unifying the ratios between the number of panicles, the number of grains and the weight of the grains, and the highest number of tillers on all the stems. The reasonable development of the tillers should be determined by the desired number of panicles. In large area production in the Shanghai area, tillering should begin about 7 days after transplanting, growth should be rapid until 15 days prior to jointing (effective tillering termination time) so that the total number of tillers and stems reaches the desired number of panicles (such as the desired number of final effective panicles of 400,000 to 500,000/mu for double season rice). Then, tillering speed must be slowed and the growth trend stabilized until after jointing when the total number of tillers and stems in a mu reaches 1.5 times the desired number of panicles (600,000 to 700,000/mu for double rice). After jointing, the number of tillers and stems begins to drop until finally the percentage of formation of panicles from tillers is about 70%, which is a favorable percentage for high yields. A survey conducted by the Shanghai Municipal Academy of Agricultural Sciences on the patterns of growth and demise of tillers of three paddy rice varieties transplanted on May 26, May 31 and June 4 respectively showed that the plants began to green 5 days after transplanting. Between the 5th day and the 10th day, an average of 20,000 tillers or more was produced a day. The rate of tillering rose most quickly between the 10th day and the 15th day averaging a daily increase of between 40,000 and 50,000 tillers/mu. After half a month, the rate of tillering slowed down. After twenty days, the peak tillering period was reached. From then on the tillers began to die out (Diagram 34).

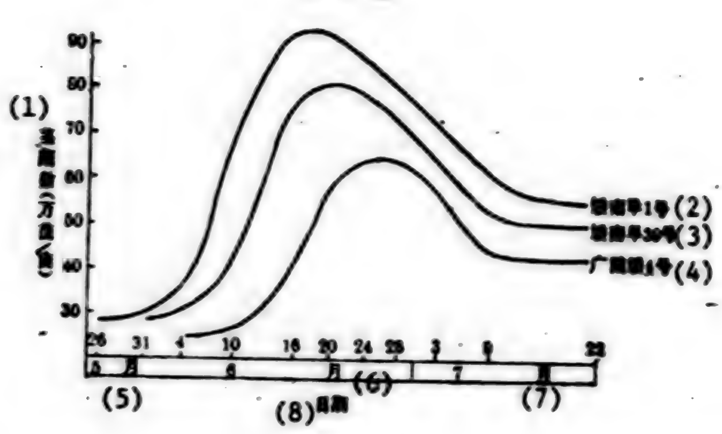


Diagram 34. Growth and Demise Curve of Tillers of Different Varieties of Early Rice (Shanghai Municipal Academy of Sciences, 1975)

Key: (1) number of stems and tillers (10,000 sprouts/mu)
(2) Ainanzao No 1
(3) Ainanzao No 29
(4) Guangluai No 4
(5) May
(6) June
(7) July
(8) Date

Diagram 34 shows the developmental trend of the colony in a normal field. During the beginning period of tillering, the number of tillers rises fast. After tillering reaches its peak, it slowly lessens, forming a normal curve distribution slanted towards the left. According to the growth and demise pattern of tillers, when the total number of tillers and stems in a mu reaches the desired number of panicles, why does the number of tillerings continue to rise, producing a number of ineffective tillers equivalent to 50 percent of the appropriate number of panicles? Studies done by concerned units believe after producing effective tillers, there must be a solidification process, otherwise effective tillers will transform and become ineffective tillers. Since a relation of simultaneous extension exists between the stem and the tillers, solidification of effective tillers must be accompanied by a definite number of ineffective tillers. For example, the double season rice produces 200,000 ineffective tillers per mu. This is an indication that the main stem and effective tillers are growing strongly and healthily and an indication of the formation of a strong plant and strong tillers. These in turn are the basis for formation of large panicles. For example, if the total number of tillers and stems in a mu has reached the desired number of panicles 15 days prior to jointing but afterwards tillering does not occur or occurs very infrequently (such as double season rice which produces a shortage of 600,000/mu), than a poor nutritional condition of the stem and tillers that emerged early is indicated. Some tillers that originally could become

panicles will transform into ineffective tillers, an unfavorable condition for the formation of strong stems and large panicles. Sometimes even when the highest number of tillers and stems has already reached the desired numerical goal, the number of tillers and stems suddenly drops drastically near jointing time. When this happens, large panicles will not be formed. At the same time, sugars, nitrogen, phosphorus, potassium and magnesium inside the body of the rice seedling can be easily transferred and retransferred (where as iron, calcium, manganese and silicon are not easily transferred). Thus, during the process of the demise of the ineffective tillers, part of these organic and inorganic nutrients may be transferred to the main stem and the large tillers for utilization. This is beneficial to the growth of the main stem and large tillers.

But when the total number of tillers and stems surpasses the desired numerical goal and continues to increase and surpasses a certain limit, then the conflict between the colony and the individual plant will sharpen. Deterioration of the conditions of light and fertilization will weaken the healthy and strong growth of the main stem and the large tillers. The percentage of formation of panicles from tillers drops, nutrients are wasted, the plants lodge easily, chlorophyll reduces, more leaves at the lower part of the plants wither, the root system weakens early, the shapes of the panicles become small, the fruiting percentage and the weight of grains drop, making high yields difficult to achieve (Table 32).

Table 32. Relationship Between Yield and Different Developments of the Colony (Jiangsu Yixing May 7 Agricultural University, 1972)

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
1	(l)	17.94	62.1	6/23	37.44	60.00	55.10	8.2	27.7	1142.2
2	(m)	16.77	84.5	6/15	44.73	56.13	38.93	28.7	26.3	915.2
3	(n)	16.84	52.2	6/25	35.55	60.70	41.90	17.8	27.7	830.8

Key: (a) field (b) item
(c) basic number of seedlings (10,000/mu)
(d) highest number of stems and tillers (10,000/mu)
(e) date of closing the rows
(f) number of panicles (10,000/mu)
(g) number of grains per panicle
(h) number of filled grains per panicle
(i) percentage of empty and semifilled grains (%)
(j) 1000 grain weight (gram)
(k) Yield (jin/mu)
(l) colony normal
(m) colony overly large
(n) colony insufficient

Table 32 shows that although the total number of tillers and stems in the No 2 field's colony reached 845,000/mu and despite the fact that more panicles

could be formed, the deterioration of light, fertilization and irrigation, poor individual development, early closing of the rows, increases in the number of withering leaves at the bottom of the plants, instability of the middle period, inability to retain the number of effective tillers, great increases in the percentage of empty and semi-filled grains and a drastic drop in the number of filled grains all caused a reduction of the number of grains per panicle. There were 16.17 grains less than that of the plants in field No 1 and the 1,000 grain weight to drop 1.14 grains compared to field No 1. The highest number of tillers and stems in field No 3 reached 522,000/mu, but then drastically dropped; the middle period was unstable. This resulted in an insufficient development of the colony and caused the number of effective tillers and the number of grains per panicle to be few. It was difficult for field No 3 to achieve a high yield. Thus the poor and lower-middle peasants says: "The major fears of high yields of paddy rice are failure to emerge in the early period (referring to the effective tillering period) and instability during the middle period."

Since the highest number of tillers of the colony directly affects the size of the colony, the time of closing of the rows and the yield of paddy rice, answers to questions concerning a specific piece of land used in production as to whether the highest number of tillers would be too much or not enough must be known during the effective tillering period so that appropriate measures can be taken in time. Under definite conditions of production, the number can be estimated from the length of the leaf calculated by taking the difference between the total number of leaves on the main stem and the number of extending internodes above ground. For example, the early rice variety "Erjiuqing" has a total of 11 leaves throughout its lifetime and 4 extending internodes above ground. Thus the leaf used to estimate the highest number of tillers is 11 - 4 = 7, i.e., the 7th leaf. By the pattern of simultaneous extension of the leaf and tiller, the last tillers of the early rice variety "Erjiuqing" are generally the 6th tiller (emerging simultaneously with leaf 9/0) and its simultaneous tillers. And since the nutrients for the 6th tiller is supplied by the 7th leaf, then if the 7/0 leaf (leaves) in the colony is generally long, prosperous growth is indicated. Thus the emergence of the 6th tiller and its simultaneous tillers is very possible. Conversely, if the 7/0 leaf is generally short, poor growth is indicated and the possibility that the 6th tiller and its simultaneous tillers will emerge is small. Thus the number of the highest number of tillers can be predicted to a certain degree from the length of the 7th leaf. The same applies to other varieties.

In addition, the pattern of formation of panicles from tillers of double season rice indicates that most of these effective tillers emerge from the 5th and 6th nodes (counting from top to bottom). The pattern of simultaneous extension of leaves and tillers indicates that when the 8th and 9th leaves of the main stem emerge from the leaf sheaths, tillers will emerge from the axils of the 5th and 6th nodes (these tillers of late maturing varieties emerge 1 to 2 leaves later). These tillers are precisely the tillers emerging during the early period and at the proper transplanting time. They generally will be able to grow into large panicles and their percentage of forming panicles is high.

In general, the number of effective panicles in high yielding fields is relatively stable. Further increases in yield are possible only by fully developing the potential of increased yield of the panicles of the main stem and the tiller panicles and increasing the number of grains per panicle and the weight of grains. Panicles of the main stem that have absolutely no tillers will not yield a large number of grains per panicle nor heavy grains. In dealing with these panicles, the conditions for formation of the panicles from tillers must be taken into consideration (such as tillering characteristics of the variety, seedling age, quality of transplanting, and conditions of temperature and fertility). [Knowledge] of tillering should be rationally used to stimulate tillering during the early period and to control tillering during the latter period. Use cultivational measures for a reasonable determination of the ratio of panicles of the main stem to the panicles of the tillers. In general, an appropriate increase in the ratio of tiller panicles is beneficial to increasing the number of grains per panicle and the weight of grains but if there are too many tillers during the latter period, then only small panicles will be formed and heading will not be uniform. These are disadvantageous to achieving high yields. Thus, according to the situation in the Shanghai area, the most appropriate ratio of panicles on the main stem to the panicles on the tillers of double season rice should be 1:0.3 to 1:0.5 in general. It is absolutely necessary to assure a sufficient number of effective panicles by planting more basic seedlings.

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CHAPTER 4. GROWTH OF THE STALK AND DIFFERENTIATION OF THE RICE PANICLE

Tillering basically ends as growth of the paddy rice plants enters the end of the tillering period. The entire plant's growth centered in the roots, leaves and tillering buds now shifts to the reproductive growth stage centered around the growth of the stems and panicles. Observed outwardly, the paddy rice seedling during its vegetative growth stage develops horizontally, the part of the plant above ground grows continuously into new leaves and tillers and the root system extends horizontally underground near the surface of the soil. The color of the leaves is deep green. When the plant reaches the reproductive growth stage, it turns to vertical growth. The roots extend downward. The stems extend upward. The color of the leaves gradually changes from deep green to light green. At the same time, the stem's apical point extends from its hemispherical shape into a panicle shape. The growth of paddy rice during this period is characterized by simultaneous growth of the vegetative organs and reproductive organs. It is the key period to simulate formation of a strong stalk and large panicles and also a period to effectively secure the number of panicles, prevent lodging and increase the weight of grains. It is a very important period in the process of cultivating high yields of rice. In this period, jointing, leafing, rooting and growth of panicles are rapid, the plant enlarges rapidly and the dry substances in the body of the plant increase very fast. Thus a lot of fertilizers is needed. It has been determined that within a period of one month, the accumulation of dry substances in the part of the plant above ground constitutes over 50 percent of the dry substances accumulated throughout the lifetime of the paddy rice plant. The absorption of nitrogen, phosphorus and potassium also constitutes 50 percent of the total amounts absorbed throughout the lifetime of the paddy rice plant. A deficiency of fertilizers during this period will result in a serious reduction in yield. With a good nutritional supply, yield can be visibly increased. This is the period in which the effectiveness of fertilizers to increase yield is developed to the utmost. Improper fertilization and management will often cause the plant to lodge, remain green, mature late or subject the plant to serious damage by diseases and insects later and cause a reduction in yield.

I. Growth of the Stalk

A. The Shape of the Stem and Its Function

The main stem of the paddy rice plant remains in a state of dormancy during the tillering period. It begins to extend and joint and internodes emerge at the end of the tillering period. When the stem has grown to 1 to 2 centimeters in length, the jointing period begins. The total number of nodes on the stems vary with different varieties. The number of internodes on the part above ground (including the stalks of panicles) varies between 4 and 7. Early rice plants sown under normal conditions generally acquire 4 internodes or 5 internodes at most. Intermediate rice plants generally acquire 5 to 6 internodes and a few acquire 7 internodes. Late rice generally acquires 5 or 7 internodes. In general, internodes at the bottom part of the plant are short and those at the upper part are long. The rice panicle emerges from the tip of the stem called the panicle stalk. The part between the flag leaf and the node of the panicle stalk is called the pedicel or panicle neck. The height of the stem varies with different varieties and conditions of cultivation, but is generally between 70 and 130 centimeters.

The shape of the stem of the paddy rice plant is like a round tube with a hollow center. The structure of the stem includes the epidermal tissue, the functional tissues and the parenchyma (Diagram 35). There are long and short epidermial cells in columnar arrangement. Parts of the walls of the short cells are lignified and silisified. The amount of silicate settled in the cell walls is related to the strength of the stem and the resistance to blast of rice. On the inner side of the epidermis of the paddy rice stem are several layers of cells with thick walls connected in rings forming a strong mechanical tissue whose degree of development is closely related to the plant's resistance against lodging. Inside the mechanical tissue are cells with thin walls containing chloroplastid or red and purple chromosomes giving the internode its green, red or purple color. Many vascular bundles are distributed throughout the thin wall tissues in dual rings of one outer ring and one inner ring. The vascular bundles on the outer ring are smaller and located along the outer rim of the stem. The vascular bundles on the inner ring are larger and are located along the inside of the stem and mostly buried within the mechanical tissue. Vascular bundles that have differentiated and developed well facilitate the transportation of nutrients and moisture up and down and connect the various organs of the body of the plant. A strong stem is significant to formation of large panicles, resistance to lodging and increasing the weight of grains because a strong stem can maintain a high nutritional level and create favorable structural conditions for differentiation and development of large panicles. When the degree of silisification of the epidermal cells of the stem wall is high, the functional tissues are developed, carbohydrates have accumulated abundantly, are transformed into lignin and cellulose and are deposited in the parenchyma, then the stem is thickened and is able to resist lodging. The more high yielding the plant, the heavier its panicles are, thus the heavier the burden the stem has to support. The function of a strong stem is not only related to the formation of large panicles and resistance to lodging but also closely related to the weight of grains. The stem, leaf sheath and leaves contain a rich store of nutrients. After heading, these stored nutrients are transported to the panicles in a dissolved state for use in flowering and fruiting. Since 1/3 of the carbohydrates of the grain after ripening originates from the substances temporarily stored in the stem, leaf sheath and

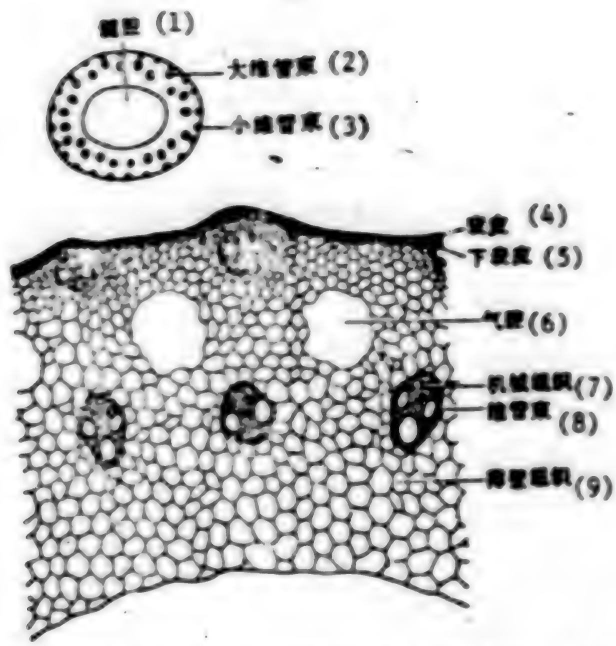


Diagram 35. Structure of the Internodes of the Stem (a part of the horizontal cross section)

Key: (1)	"spinal" cavity	(6)	air cavity
(2)	vascular bundle trunk	(7)	mechanical tissues
(3)	vascular bundle	(8)	vascular bundle
(4)	epidermis	(9)	parenchyma
(5)	lower epidermis		

leaves before heading, a strong stem with a lot of accumulated substances will increase the amount of nutrients transported to the grains after heading. This is an important function of the stem in increasing the percentage of fruiting and weight of grains.

B. How the Stalk Grows

The paddy rice stalk grows in two ways: apical growth and intercalary growth. Growth is by negative geotropism.

1. Apical Growth

During vegetative growth, the apex of the rice stalk is hemispherical in shape. It consists of a bunch of meristematic tissues called apical meristems which have a strong capability to divide. The cells of apical meristems continue indefinitely to divide, elongate and differentiate resulting in the increase in the number of nodes and production of leaf primordia and tillering bud primordia.

2. Intercalary Growth

As the apical meristems at the tip of the stem of the rice stem differentiate into nodes and internodes, some of the meristematic tissues remain at the base of the internodes. These tissues are called intercalary meristematic tissues. The internodes elongate because of cell division of the intercalary meristematic tissues. The intercalary growth and beginning of elongation of internodes at the base of the rice stem are called jointing. At heading, the extension of the stem is especially fast. This is the result of simultaneous intercalary growth of several internodes.

At the beginning, the growth of the stem mainly occurs at the tip to form new nodes of the stem and leaves and differentiation of young panicles. When differentiation of young panicles is completed, the growth of the tip ceases and the plant enters jointing and heading as the characteristics of intercalary growth.

C. Formation and Developmental Process of the Stalk

The formation and the development of the stalk can generally be divided into the following four stages:

1. Tissue Differentiation Stage

The process of formation of the stem of the paddy rice is like that of other higher plants. It involves the differentiation of the cells of apical meristematic and protoplastic tissues of the stem into various protoplastic meristems. These protoplastic meristems further differentiate into various mature tissues, such as the vascular tissue, the mechanical tissue and the parenchyma. The tissue differentiation stage is the period in which the basis for a strong stem is preliminarily established. The differentiation stage of the internodal tissues at the base of the stem is completed during the latter period of tillering. Sufficient light and appropriate amounts of nitrogen must exist during the tissue differentiation period. If nitrogen is supplied under conditions deficient in the amount of light, differentiated tissues will be soft. Given conditions of sufficient light and deficient fertilization, the intensity of differentiation will be weakened, making the plant susceptible to lodging during the latter period of growth.

2. Internodal Elongation Stage

Based on tissue differentiation of the previous period and following the rapid growth of intercalary meristematic tissues of the internodes, the paddy rice seedling begins to joint. This is the critical period that determines the length of the internodes and also affects the thickness of the internodes. The paddy rice plant usually has 4 to 7 jointing internodes (varying according to different varieties). Those internodes below the IV to VII nodes (counting from top to bottom) generally do not elongate. Jointing usually

begins from the internodes at the base of the plant and then gradually progresses upward (Diagram 36). From the point of view of cultivating high yields, the internodes at the base of the plant should be short and thick. This will increase the plant's resistance to lodging. Therefore, when the internodes begin to elongate, fertilization and irrigation are controlled to suppress elongation of the cells so that the internodes will become short and thick. Sufficient light and appropriate control of nitrogenous fertilizers can suppress over elongation of the cells of the internodes. Under ordinary conditions, if the growth trend is not too weak, the water in the field must be dried and the field drained at the end of tillering and at the beginning of jointing so that light conditions can be improved, the roots can be stimulated and the growth of internodes controlled to prevent lodging. The length of the internodes and their concentration are also related closely to the different varieties. Since the internodes of dwarfed stem varieties are short and concentrated, the plants have a low center of gravity, the weight of dry substances in a unit length at the base of the stem is higher than that of tall varieties and the mechanical tissues are developed, thus they possess the characteristics of tolerance to fertilizers and resistance to lodging.

3. Material Filling Stage

During the period, the mechanical tissue of the internodes and the cell walls of the thick walled cells are filled by lignin and cellulose produced from the transformation of starch. At the same time, the epidermis of the stem wall silisifies and large amounts of starch accumulate in the thin walled cells. The massive accumulation of the above substances gradually makes the stem increase in girth. This period is the crucial period that determines the strength of the stem at the internodes. The major source of material for filling the internodal tissues and causing the stem to increase in girth is photosynthesis. Filling of the internodes at the base of the stem is most closely dependent upon the photosynthetic products of the leaves at the lower part of the stem. If the rows close too early and dense growth is rampant at the time when the internodes of the base of the plant are filling, then the leaves will not be able to receive sufficient light and assimilation of nitrogen will be weak. This will cause a deficiency or lack of carbohydrates needed in filling the base of the stem and cause poor filling of the internodes at the base of the stem. Thus lodging will likely occur after heading. As such when cultivating high yields proper control of the time the rows close is very important in preventing lodging. The internodes at the base of the plant require between 7 and 8 days to elongate and reach maximum length.

4. Material Exportation Stage

Starting from heading and flowering, the large amount of starch stored in the stem is hydrolyzed again and is transported to the panicles as dissolved carbohydrates mainly for flowering and fertilization, for filling and ripening of grains and for increasing the weight of grains. At this time, the dry weight of the stem drops.

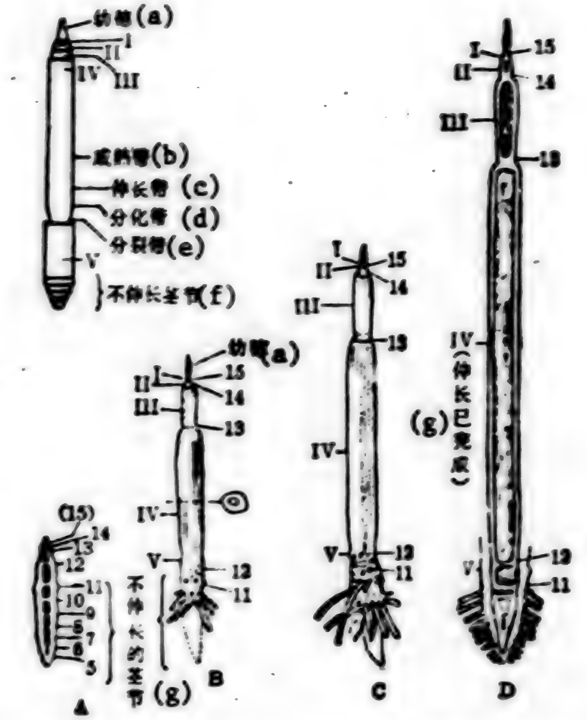


Diagram 36. The Process of Elongation of Various Internodes of the Stem During the Beginning Period of Internodal Elongation of Paddy Rice (Taken from Hoshigawa Kiyoshin 1975)

Upper leaf: model Below: elongation process (A→D)

Key: (a) young panicle
(b) maturation zone
(c) elongation zone
(d) differentiation zone
(e) division zone
(f) node of stem that does not elongate
(g) elongation is completed.

Remark: Arabic numerals indicate nodes counting upwards. Roman numerals indicate internodes counting downward.

The relationship between filling and elongation of the internode of the stem is as follows. As the Nth internode begins to elongate, the N-1 internode (the one below) is rapidly filling and the N-2 internode (the second one below) is at the end of the filling stage and about to develop and firm up.

There is a close relationship between the growth of the paddy rice stem and differentiation and formation of the panicles. The Jiangsu Academy of Agricultural Sciences experimented with 16 varieties in 1972. They were sown at 13 different times and the relationship among the growth of the various organs

was observed. Results showed a very close relationship between young panicle differentiation and elongation of internodes. It was observed that regardless of whether 6th internode (the 6th internode counting from top to bottom, including those on the stalk of the panicle) has visibly extended or not, young panicle differentiation always began about the time the 6th internode ceased to extend. Thus, the timing of jointing and young panicle differentiation is mainly determined by the number of internodes that have extended (Table 33).

Table 33. Relationship Between Elongation of the Various Internodes of the Paddy Rice Plant and the Progress of Panicle Differentiation

(a) 穗分化进程		(c)	(c)	枝梗分化 (d)	颖花分化 (e)	花粉母细胞减数分裂 (f)	花粉粒充实(孕穗期) (g)	抽穗期 (h)
(b) 各节间伸长(自上而下数)		第7节间	第6节间	第5节间 (c)	第4节间 (c)	第3节间 (c)	第2节间 (c)	穗梗 (c)
不同伸长节间数的植株节间伸长(自下而上)情况 (i)	7个节间植株 (j)	1	2	[illegible]	4	5	6	7
	6个节间植株(j)		1	2	3	4	5	6
	5个节间植株(j)			1	2	3	4	5
	4个节间植株(j)				1	2	3	4
	3个节间植株(j)					1	2	3

Key: (a) progress of panicle differentiation
(b) elongation of each internode (counting from top to bottom)
(c) ___ internode
(d) Differentiation of branch stalk
(e) Differentiation of spikelet
(f) Meiosis of pollen mother cell
(g) Filling of pollen (panicle bearing stage)
(h) heading period
(i) elongation of internodes of plants having different numbers of extending internodes (counting from bottom to top)
(j) Plants with ____ internodes

Three situations arise from the timing of jointing and young panicle differentiation: One is jointing occurs after the young panicles begin to differentiate. The other is jointing occurs before the young panicles differentiate. The third is jointing occurs simultaneously with the beginning of young panicle differentiation. According to the relationship between jointing and young panicle differentiation, distinctions can be made for three types, "overlapping, connecting and separated" (referred to on Page 3 to 5). Since different varieties have different types of growth, different measures should be taken. For example, the overlapping type has a short tillering period, thus fertilizers for tillers must be applied early and heavily. The separated type begins young panicle differentiation after jointing and growth easily weakens during the latter period, thus the application of fertilizers for panicles is important.

II. Differentiation of Young Panicles

After the paddy rice plant completes a definite period of vegetative growth, it begins to enter the reproductive growth period of young panicle formation. This change is called the transition of growth stages. The beginning of young panicle differentiation is the starting point of transition of vegetative growth towards reproductive growth. Young panicle differentiation of peddy rice follows an internal order. Understanding the development and progress of young panicles are important in guiding distribution of varieties, arrangement of openings in crop rotation and management of seedling age and fertilization and irrigation in the large fields.

The leaves and the panicles of paddy rice are the results of differentiation of the apical point at the tip of the stem. The apical point differentiates into the leaf primordium and the leaf primordium grows into a leaf. When the paddy rice plant develops to a certain stage, a qualitative change occurs in the meristematic tissue of the stem. Differentiation of leaf primordia ceases. Differentiated young panicles suddenly emerge and then after a series of differentiating stages the young panicle gradually grows into the paddy rice panicle. The duration of young panicle differentiation of paddy rice (from the time the apical point of the stem begins to differentiate to the beginning of heading) varies with different varieties, climates, conditions of cultivation, management methods of fertilization and irrigation. In general, single season late rice requires the most number of days to complete differentiation, followed by intermediate rice and early rice which requires the least number of days for differentiation. Generally the duration from differentiation of the young panicle to heading is between 27 and 30 days for early rice, and between 30 and 35 days for late rice. The duration between heading and maturity is about 30 days for early rice, between 30 and 40 days for intermediate rice and about 45 days for late rice.

A. Shapes of the Rice Panicle and Spikelet

The rice panicle has a composed recemose inflorescence also called a panicle consisting of a panicle axis, the primary branches, secondary branches and a spikelets. The central axis of the panicle is the main stalk, i.e., the panicle axis. The axis has panicle nodes. Branch stalks growing from the panicle nodes are called primary branches. Small branches growing from the primary branches are called secondary branches. Tertiary and fourth branches can emerge from the secondary branch. The pedicel growing from the primary or secondary branches have small panicles growing from their tips called spikelets. Each small panicle generally has only one spikelet. (See Diagram 37).

The rice panicle grows on the panicle neck. The panicle neck is the uppermost part of the internode of the stem. The length from the panicle neck node to the earlet of the flag leaf is also called the extension of the panicle. The length of the panicle neck varies with different varieties and is a visible physical characteristic for classification of the varieties.

Diagram 37. The Shape of the Rice Panicle

Key: (1) spikelet
(2) secondary branch
(3) primary branch
(4) panicle axis
(5) panicle node

The bottommost node of the panicle is the panicle neck node. At the panicle neck node, each primary branch extends from the panicle axis at a 2/5 opening angle. On some varieties, the several panicle nodes at the base of the panicle are connected together. In this way, 2 to 3 branches thus grow nearly symmetrically or verticillately. Due to environmental conditions, some of the primary and secondary branches at the lower part of the panicle degenerate. Even at maturity, marks of these degenerated branches can still be seen.

The length of the panicle varies greatly with different varieties, conditions of cultivation and the order of tillering. Short panicles measure only about 10 centimeters long but in general the rice panicle measures about 20 centimeters. The number of branches also vary greatly. Panicles with 10 to 15 branches are the most common.

A spikelet consists of rudimentary glumes, sterile lemmas, lemma, palea, scales (cuticles), pistils and stamena (Diagram 38). The palea and lemima are generally called the grain husk. The lemma is shaped like the bottom of a boat. It has five vascular bundles and its surface is covered with pubescence. The lemma of some varieties has awns extending from the tips.

Xian rice generally does not have awns or the awns are short. Geng rice generally has rather long awns. Varieties with awns have a stronger resistance to adverse environments. It is generally believed the physiological function of awns is to assist evaporation of moisture at the time the grains ripen. The awns are also the places where photosynthesis takes place and are thus able to provide nutrients to the grains. The palea and lemma are similar to shape but the palea is narrower and only has three vascular bundles. The palea and lemma generally are green prior to ripening. After maturity they become yellow or mixed with other colors. On the insides of the palea and the lemma are two scales (cuticles) which are flat, colorless and thin fleshy plates that house the spiral ducts. The opening and closing of the spikelet is due to expansion and contraction of the scales as a result of absoring or losing moisture. There are six stamina growing at the base of the ovary. The stamen consists of the filament that supports it and the anther. There are four chambers in the anther. Each chamber constitutes a pollen sac. Each sac contains many yellow spheres which are the pollen. The pollen grain of paddy rice contains rich amounts of starch, sugars, amino acids, vitamins and enzymes as the nutritional source for germination of the pollen grain. There is one pistil in the center of the spikelet. The pistil has an ovary, style and stigma. The stimga is split in the shape of a feather. It is the part which receives pollen during pollination. The style may be colorless or may have color (purple, red) which is characteristic of the variety. The ovary is shaped like a stick with an ovule surrounded by inner and outer ovule coats. The ovule has an opening at the top. Inside the ovule coats is the ovule core composed of thin walled cells. Inside the ovule core is the embryo sac.

B. Differentiation Process of the Young Panicle

Young panicle differentiation basically is a continuous process. For convenience, it has been divided artificially into several periods. In China, Ding Ying (0002 4481) divided young panicle differentiation into eight periods according to the actual situation of differentiation of the young panicle coupled with the needs required by techniques of cultivation: first bract differentiation period, primary branch differentiation period, secondary branch and spikelet primordium differentiation period, pistil and stamina formation period, pollen mother cell formation period, meiosis of pollen mother cell period, pollen filling period and pollen completion period. The Jiangsu Agricultural College combined the eight periods above into four periods according to the young panicle differentiation process and structure of the panicle, outer form of the plant and the need of cultivation: branch differentiation period, spikelet differentiation period, meiosis of pollen grain formation period.

1. Branch Differentiation Period

The branch differentiation period is the period in which the total number of branches is determined. It includes the differentiation of the primordium of the first bract, the differentiation of the primordium of the primary

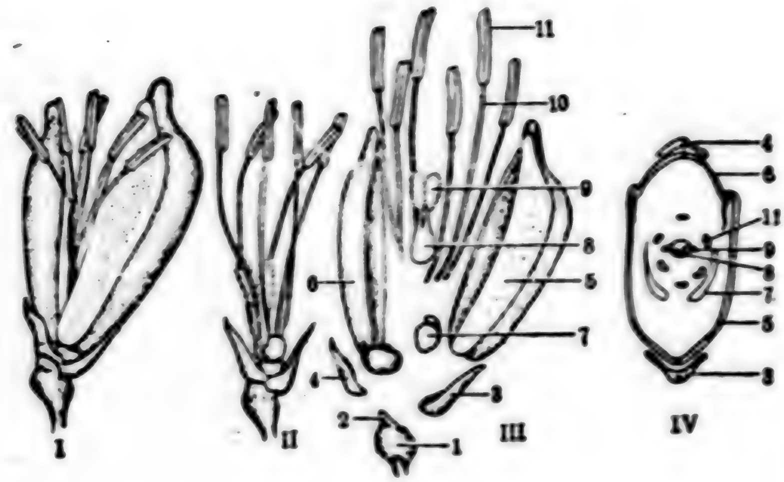


Diagram 38. Structure of the Spikelet

I. Outer shape of the spikelet at flowering
II. Inside view of the spikelet at flowering (after removal of the inner and outer glumes)
III. Parts of the spikelet
IV. Inflorescence
1. First rudimentary glume; 2. Second rudimentary glume;
3. First sterile lemma; 4. Second sterile lemma; 5. Lemma;
6. Palea; 7. Scale; 8. Ovary; 9. Stigma; 10. Filament; 11. Anther.

branch and the differentiation of the primordium of the secondary branch. (Diagram 39). At this time the young panicle is very small and can be identified and observed only through anatomical lenses or under the microscope.

(1) Differentiation of the Primordium of the First Bract:

Differentiation of the young panicle beings with the emergence of the primordium of the first bract as a ring shaped protuberance at the upper part of the primordium of the flag leaf at the base of the apical meristems of the stem. At the beginning period of differentiation of the primordium of the first bract increases, the apical meristems gradually enlarge to a greater degree. The emergence of horizontal wrinkles on the apical meristems marks the end of the differentation period of the first bract. The primordium of the first bract will differentiate and develop into a bract. The bract is the progenitor of leaves. The bract grows on the node of the panicle axis. The "axis bud" in the axis of the bract will develop into a primary branch but the bract degenerates and does not grow. The second bract, third bract... emerge immediately following differentiation of the primordium of the first bract. The axis of each can develop into a primary branch. The period of differentiation of the primordium of the first bract signifies the beginning

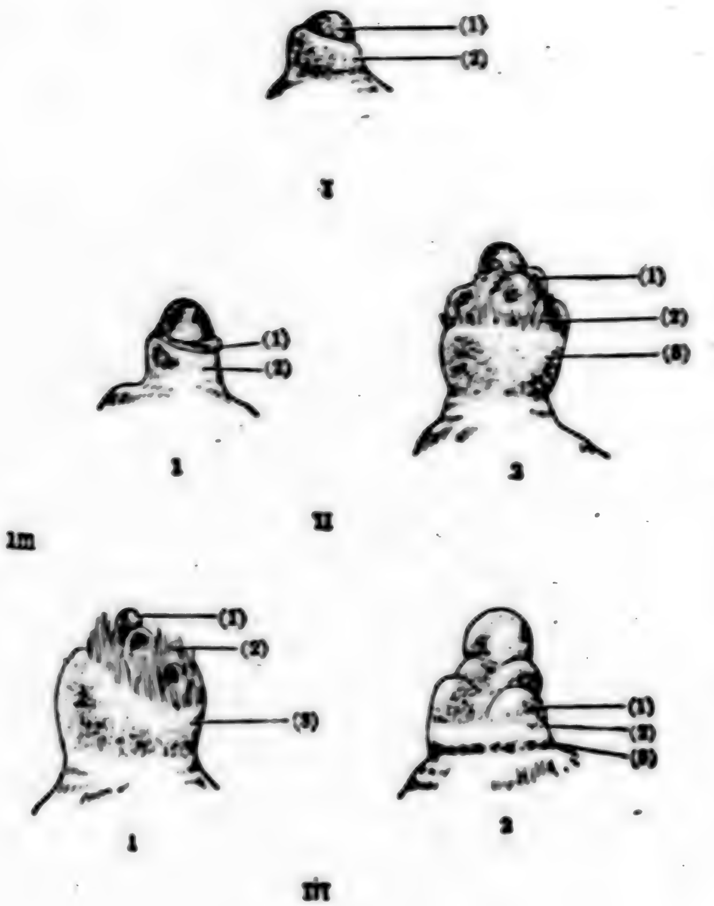


Diagram 39. Differentiation of Branch Stalks

I. Differentiation of the first bract
   1. apical meristem   2. bract

II. Differentiation of the primary branch
   1. young panicle at beginning of differentiation:
      (1) horizontal wrinkles emerge on apical meristem (2) bract
   2. young panicle at latter period of differentiation.
      (1) primordium of primary branch (2) pubescence of bract (3) bract

III. Differentiation of primordium of the secondary branch:
   1. at beginning of differentiation
      (1) primordium of primary branch; (2) pubescence of bract; (3) bract
   2. A branch stalk taken from 1:
      (1) primordium of secondary branch;
      (2) pubescence of bract   (3) bract

of reproductive growth and young panicle differentiation. However, the first bract and the leaf primordium are very similar in appearance and it is not easy to tell them apart. Since the apical meristems are small and cannot be easily disected, early determination of the emergence of the primordium of the first bract is difficult and it is difficult to popularize and apply the practice in production.

(2) Differentiation of the First Primordium of the Primary Branch:

The new conical protuberance that emerges from the axil of the bract is the primordium of the primary branch. The order of differentiation of the primary branch begins from the bottommost part of the apical meristem and progresses from bottom to top towards the tip of the apical meristem. However, the growth of the primary branch is in the reverse order, from top to bottom, i.e., the most recent upper branch stalk grows the fastest. After the differentiation of the primary branch ends, a white pubescence appears on the bract. For the convenience of application in production, the emergence of the primordium of the primary branch is regarded as the indicator of the beginning of panicle differentiation.

(3) Differentiation of the Primordium of the Secondary Branch:

Differentiation of the primordium of the secondary branch begins with the protuberance emerging on the foundation of the differentiation of the primary branch. The characteristic of the differentiation of the primordium of the secondary branch is that the apical point at the tip of the panicle axis ceases its growth while the primary branch at the tip that is the last to differentiate grows more rapidly than the primary branches at the base which had differentiated earlier. Thus, the order of differentiation of the primordium of the secondary branch is the reverse of the order of differentiation of the primordium of the primary branch, i.e., differentiation proceeds from the tip of the panicle downward towards the base of the panicle. At this time, the young panicle is covered by a dense and thick covering of pubescence and the young panicle can be seen by the naked eye.

The period of branch differentiation is the period in which the number of branches is determined. In general, the more secondary branches there are, the more spikelets there will be.

2. Differentiation of spikelets

The spikelet differentiation period is the period in which the total number of spikelets is determined. This period includes differentiation of the primordium of the spikelet, the stamina and the pistil (Diagram 40). Differentiation of the primordium of the spikelet begins with the emergence of the protuberance in the shape of a tumor at the tip of the primary branch--the beginning of the primordium of the spikelet. Each tumor-like protuberance is encicled by a ring of protuberance shaped like an arc. These are the primordia of the lemma, the palea and the sterile lemma. At this time, the

young panicle's length is about 1 millimeter. After the primordium of the spikelet emerges from the tip of the primary branch, another emerges on the next primary branch below and the secondary branch consecutively. The order of differentiation of the primordium of the spikelets on the entire panicle is from top to bottom. For every two secondary branches on the primary branch, spikelets of the secondary branch on the top differentiate first and are then followed by those on the secondary branch below. On every primary or secondary branch, the order of differentiation of the primordia of spikelets begins at the tip where the spikelet differentiates first and then is followed by differentiation of the spikelet at the base of the branch stalk, and then from bottom to top to the second spikelet on the branch which is the last to differentiate. This order of differentiation is the same as the order of flowering and maturation, i.e., 1,6,5,4,3,2, or 1, 3, 2. In general, spikelets that differentiate early have a higher fruiting percentage because they have a sufficient supply of nutrients.

Further differentiation of the primordium of the spikelet constitutes the stamina and pistil differentiation priod. Small protuberances that emerge inside the spikelet are the primordia of the pistil and the stamina. The spikelet continues to differentiate and the sterile lemmas and lemma begin to extend. At the beginning the sterde lemmas grow faster. Later the palea and lemma grow faster than the sterile lemmas. They gradually extend upward and develop until they finally meet each other. During this same period, the inner part differentiates further. The anther and the filament differentiate from the stamen and the primordium of the ovule differentiates from the pistil, the cuticle plates can now be clearly seen. The young panicle at this time is between 5 and 10 millimeters long. The outer shape of the young panicle is now in its initial form. The naked eye can see clearly the preliminary form of the panicle and the spikelet.

During the process of differentiation and development of the young panicle, not all of the primordia of spikelets that differentiated develop into a spikelet. Some of them develop into degenerate spikelets. In some cases, all the spikelets on a branch degenerate. This branch is then called a degenerate branch. Over 90 percent of the degenerate spikelets cease to grow during differentiation of the stamina and the pistil, and the majority ceases to grow by the time the palea and lemma have grown together and have completely enveloped the stamina and the pistil. The Jiangsu Agricultural College's Crop Cultivation Teaching and Research Group (1972) examined over 1000 degenerate spikelets on 70 rice panicles of different varieties and of plants cultivated by different methods. Only 3 spikelets ceased development prior to formation of the stamina and pistil. The majority (90 percent 98.7 percent) ceased development during the period of formation of the stamina and the pistil. A few ceased to develop after formation of the pistil and stamina. Thus, in general, after emergence of the primordium of a spikelet, differentiation continues until at least the period of formation of the pistil and the stamina.

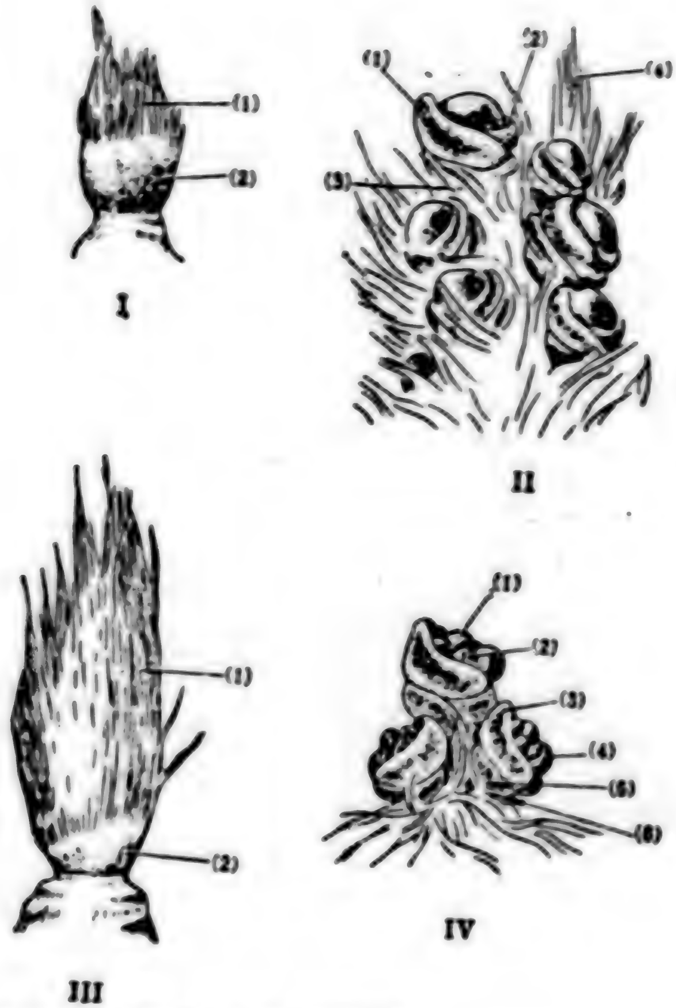


Diagram 40. Differentiation of the Spikelet

I. Young panicle at the beginning of spikelet differentiation
(1) pubescence of bract (2) bract

II. A branch taken from I: (1) primordium of lemma (2) primordium of palea

III. Young panicle after differentiation: (1) pubescence of bract; (2) bract

IV. A branch taken from III: (1) primordium of pistil (2) primordium of stamena; (3) primordium of lemma; (4) primordium of palea; (5) primordium of lemma of sterile spikelet; (6) primordium of sterile lemma.

3. Meiosis of the Pollen Mother Cell

The period of meiosis of the pollen mother cell is the key period in which the fruiting and the capacity of the grain (the sixe of the husk) is determined, i.e., whether the spikelet will grow healthily and soundly. By this time, progress of internal differentiation has reached the formation of reproductive cells and the entire process of meiosis and the formation of pollen grains (sporophyte) are completed (Diagram 41). The size of the young panicle rapidly enlarges. The length of the panicle which is less than 2 centimeters at the beginning rapidly grows to over 10 centimeters, reaching over 70 percent of its final length. The spikelets also rapidly enlarge. In a short period of 4 to 5 days, the spikelet grows to about 80 percent the length of the mature grain. The rapid enlargement of the young panicle and the spikelet causes a sharp shortage in the distribution of nutrients in the panicle and the spikelets differentiate towards the two extremes of becoming effective spikelets or degenerates. The weaker spikelets at the lower end of the panicle easily degenerate. The degenerate spikelets mostly cannot continue to develop after formation of the pistil and stamina. All of the spikelets on one branch may degenerate forming a white protuberance, a mark of degeneration of the secondary branch or the primary branch. Under ordinary conditions, about 20 percent to 30 percent of the total number of spikelets degenerate. This is a problem in production which needs to be studied and solved. The percentage of spikelet degeneration is a characteristic of the variety and is also closely related to conditions of cultivation.

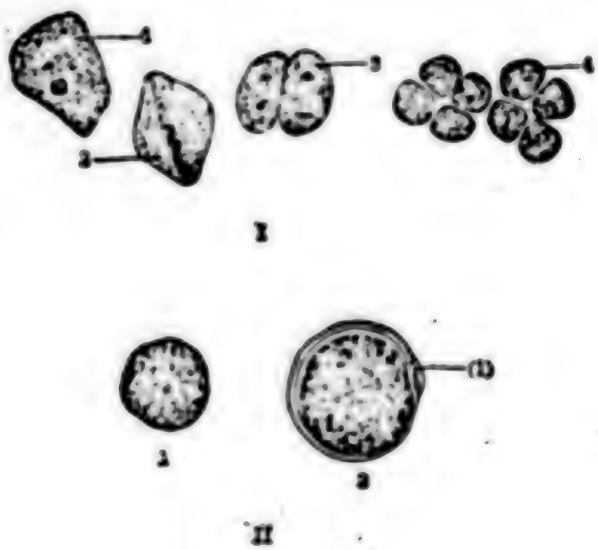


Diagram 41. Meiosis of Pollen Mother Cells and Completion of Filling of the Pollen Grain

I. Meiosis of the pollen mother cell during development
   1. Pollen mother cell; 2. two small cells are formed from the first division; 3. the second division begins; 4. four cells are formed after completion of the second division.

II. Completion of filling of the pollen in development
   1. The developing pollen grain. 2. the completely developed pollen grain (1) Pollen tube opening.

4. Pollen Grain Filling and Completion Period

The pollen grain filling and completion stage is the period when the plant has outwardly become "pregnant." The plant has enetered the panicle bearing stage. The length of the panicle is already established and the main activity is the filling of the pollen. The pollen which contains many starch granules is yellow. One to two days before heading, the nuclei undergo division and formation of the male nuclei and the fusion nucleus is completed. The period when the pollen can function normally is the period of pollen completion. At this time large amounts of chlorophyll emerge in the palea and lemma. The filament rapidly extends and the pistil and ovary mature further. When the stamina and the pistil have completely developed, the plant begins to head and flower.

The relationship between young panicle differentiation and the rice panicle can be clearly seen from Diagram 42.

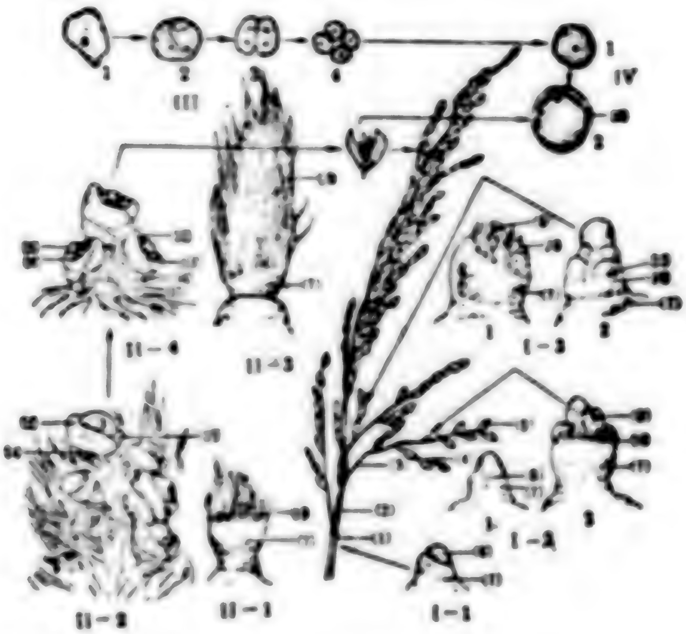


Diagram 42. Relationship Between Young Panicle Differentiation and the Rice Panicle

I. Branch differentiation: I-1. First bract differentiation; I-2. Primary branch primordium differentiation: 1. Horizontal wrinkles emerge; 2. Primary branch primordium differentiation; I-3. Secondary branch primordium differentiation. 1. Outer shape; 2. A branch taken from 1.

II. Spikelet differentiation: II-1 Appearance during spikelet differentiation; II-2. A branch taken from II-1; II-3. Appearance of stamina and pistil; II-4. A branch taken from II-3.

III. Meoisis of pollen mother cell: 1. Pollen mother cell; 2. First division; 3. Second division; 4. Four haploid cells.

[caption continued]

[caption for diagram 42 continued]

IV. Pollen grain filling and completion: 1. The developing pollen grain; 2. The completely developed pollen grain

Explanation: (1) panicle node (2) panicle axis (3) primary branch (4) secondary branch (5) spikelet (6) apical meristem (7) bract (8) horizontal wrinkles (9) primary branch primordium (10) pubescence of bract (11) secondary branch primordium (13) lemma primordium (13) palea primordium (14) sterile spikelet primordium (15) pistil primordium (16) stamina primordium (17) sterile lemma primordium (18) pollen tube opening.

Appendix: Growth and Development of Pollen and Embryo

1. Meoisis of pollen mother cells

When the young panicle extends from 1 centimeter to 4 or 5 centimeters, cell differentiation occurs inside the small anther, are the progenitors of pollen. After pollen mother cells are formed, they enlarge to become spheres and then undergo meiosis. The pollen mother cell like other cells in the body of the paddy rice plant, has a diploid of chromosomes in the nucleus, i.e., 24 chromosomes. As the pollen mother cell develops by meiosis to form pollen, the nucleus contains only a haploid of chromosomes, i.e., 12 chromosomes. Meiosis of the pollen mother cell includes two continuous cell divisions, reduction and first division (abbreviated as division I) and reduction and second division (abbreviated division II). Each division includes a prophase, metaphase and telophase. Meisosis of the paddy rice occurs when the young panicle is about 5 to 10 centimeters long and the spikelet is about 3 to 5 millimeters long. The method of observing meiosis of the pollen mother cell is to take aplant and remove its leaves exposing the young panicle. Then select a sipkelet of appropriate size, open up the spikelet, take out the anther and place it on a glass slide with a drop of acetic acid carmine dye (Preparation of acetic acid red dye: Mix 45 milliliters of iced acetic acid in 55 milliliters of distilled water and then heat until boiling. Measure 1 gram of carmine powder and add to the solution. Stir the mixture until as much as the carmine will dissolve as possible. Then cool and filter away the sediments and place filtered solution into a drop bottle.) Place a spreader slide on top and press to break the anther and spread the pollen cells.

Place the slides with their content aside for over 10 minutes so the cells are stained and then observe under the microscope. Observations by Hu Jiu-qing (5170 0036 3237) (1963) described emiosis of the paddy rice pollen mother cells as follows (See Diagram 43-1, -2 below).

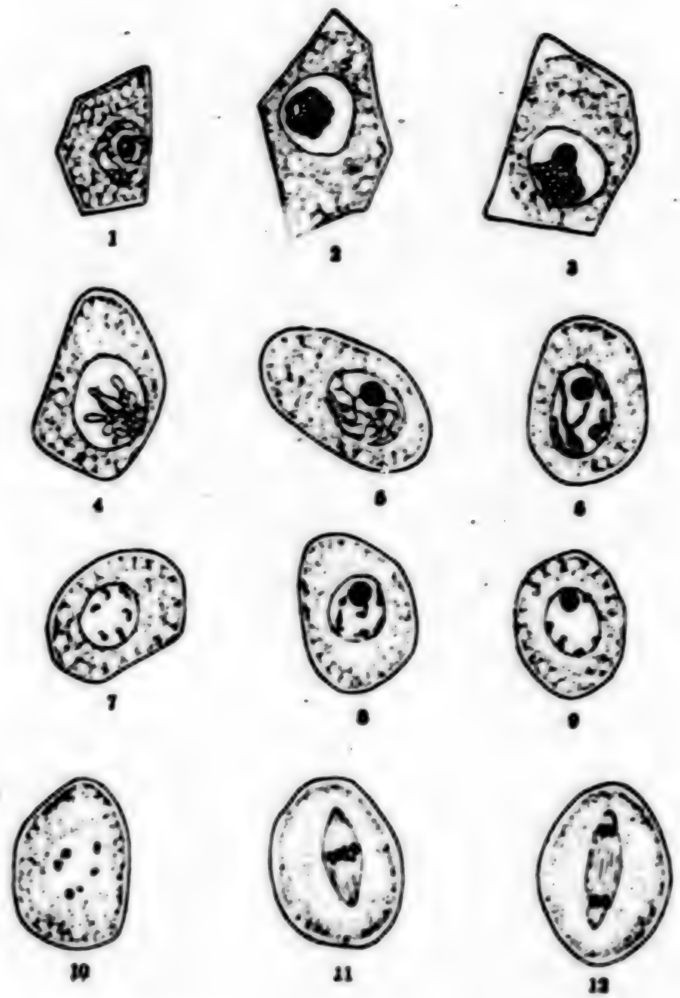


Diagram 43-1

First division (mitosis):

Prophase I (1-10):

1. Early prophase (thin thread): The cell and the nucleus rapidly enlarge in size. The nucleus and the nucleolus visibly enlarge and thin, long chromosomes appears.

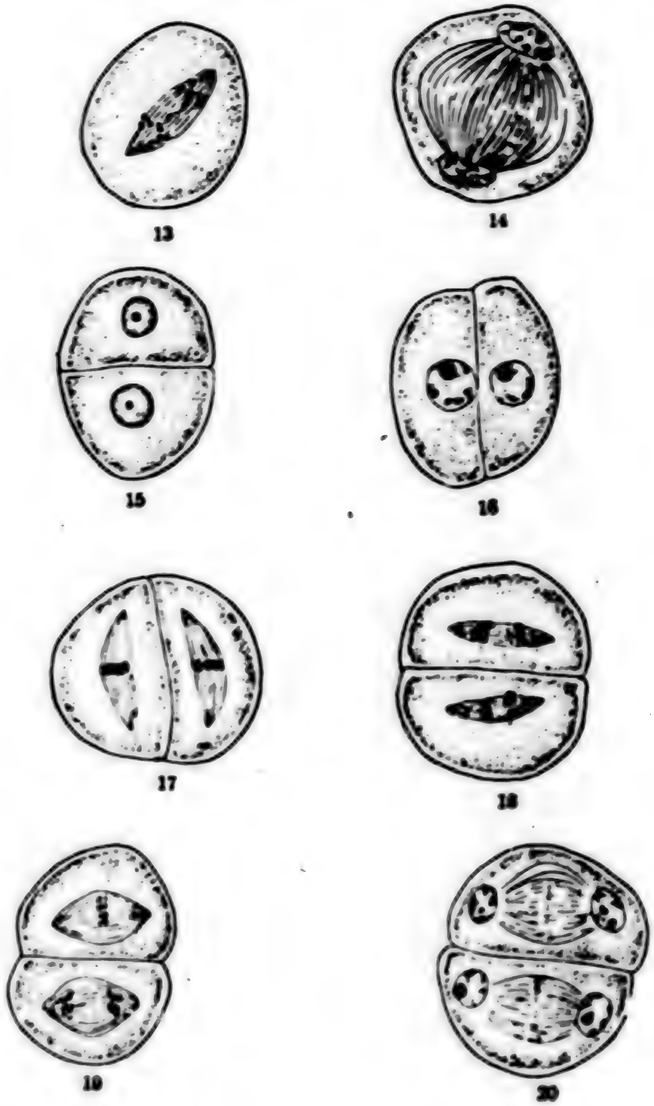


Diagram 43-2

2. Middle prophase (centromere): The nucleolus stays to one side and the chromosomes are held together in a centromere.

3-5. Middle prophase (chromatid): The chromosomes that gather in a centromere now disperse and form "flowery" forms or daughter chromosome (chromosomes of the same content, similar size and shape) pairs called chromatids.

6. Middle prophase (thick thread): Chromatids thicken and become short.

7. Late prophase (double thread): The chromatids continue to thicken and shorten and appear coiled (shaped like a coil).

8-10. Final prophase: Chromatids condense to become shorter and thicker. Twelve pairs of granular chromosomes can be seen. This is the best moment to observe the chromosomes slide. At the end of the final prophase, the nucleus further enlarges and spindles appear. The nucleolus and the nuclear membrane disappear and the prophase of reduction and first division ends.

Metaphase I (11): After the nucleolus and the nuclear membrane disappear, the chromosomes line themselves up at the "equatorial plane." A spindle is stretched between the two poles of the nuclear region.

Anaphase I (12): The daughter chromosomes move in opposite directions toward the two poles.

Telophase I (13-15): After the chromosomes reach the two poles of the spindle, they condense and the nucleolus and nuclear membrane reappear, forming two new nuclei, then a cell plate and two cells. At this time the number of chromosomes in the nucleus of each cell is halved to form haploids.

Second Division (Similar to ordinary mitosis):

Prophase II (16): This period is short. The spindles form and remain until the next division period.

Metaphase II (17): Bivalents line up at the equatorial plane and the unclear membrane disappears and spindles appear.

Anaphase II (18-20): Each bivalent's two chromosomes move apart in mitotic division towards opposite poles.

Telophase II (21-23): The chromosomes at the two poles form new nuclei each containing one chromosome of the mother cell. Four cells of haploid chromosomes are formed. These continue to develop and separate to become four pollen grains.

2. Development of the pollen

As mentioned above, the quadruplet formed after reduction and division soon disperses as four cells, each containing one nucleus. This is the young monospore pollen grain (or called mononuclear pollen, also called microspore). The outer coat of the pollen is gradually formed, the size of the pollen increases and the pollen tube opening emerges. At this time the spikelet grows to 80 percent of its entire length. The rapid longitudinal extension of the palea and lemma shapes the entire spikelet into a

Diagram 43. Meiosis of the Paddy Rice Pollen Mother Cell
Explanation:
First Division
Prophase: 1. Early prophase (thin thread)
2. Middle prophase (centromere)
3-5. Middle prophase (chromatid)
6. Middle prophase (thick thread)
7. Late prophase (double thread)
8-10. Final prophase

Metaphase: 11. Reduction and first division metaphase
Anaphase: 12. Reduction and first division anaphase
Telophase: 13-15. Reduction and first division telophase

Second Division
Prophase: 16. Reduction and second division prophase
Metaphase: 17. Reduction and second division metaphase
Anaphase: 18-19. Reduction and second division anaphase
20. Reduction and second division anaphase
Telophase: 21. Quadruplet:
22. Mononuclear young pollen grain
23. Young large pollen grain (pollen megaspore) having four nuclei.

thin and lengthy form. The outer coat of the pollen continues to develop and the size of the pollen continues to increase. As the pollen is filled the cells inside the pollen divide to form one reproductive nucleus and one vegetative nucleus as a two-nuclei (spore) pollen grain. During the latter period of the two-nuclei pollen grain, the palea and lemma's longitudinal extension ceases. Two days prior to heading, the pollen fills up. This is the pollen grain's completion stage. At heading and flowering, the reproductive nucleus in the pollen grain divides to form two reproductive nuclei

(sperms) and one vegetative nucleus, becoming a 3 nuclei (spore) pollen grain. At this time the male cell of the three-nuclei pollen grain is formed, and the pollen grain contains a large accumulation of starch and other nutrients. Also at this time the filaments su[illegible]ly extend and the plant flowers. The mature three-nuclei pollen grain is released (Diagram 44).

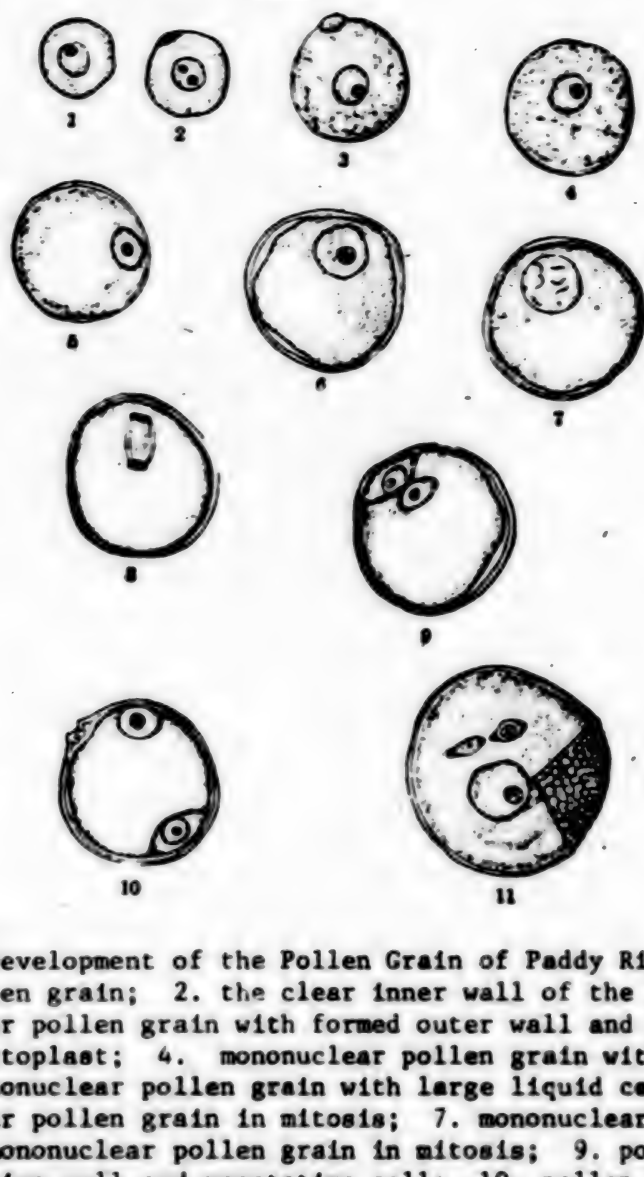


Diagram 44. Development of the Pollen Grain of Paddy Rice
1. young pollen grain; 2. the clear inner wall of the young pollen grain; 3. mononuclear pollen grain with formed outer wall and emergence of liquid cell in the cytoplast; 4. mononuclear pollen grain with expanding liquid cell; 5. mononuclear pollen grain with large liquid cell at center; 6. mononuclear pollen grain in mitosis; 7. mononuclear pollen grain in mitosis; 8. mononuclear pollen grain in mitosis; 9. pollen grain divided into reproductive cell and vegetative cell; 10. pollen grain with two spores and the vegetative cell is moving to the other side; 11. mature pollen grain having two sperm cells and one vegetative cell.

3. Formation and Development of the Embryo Sac

The female reproductive cell is formed in the ovule of the ovary. The ova y of paddy rice has only one ovule. The ovule first emerges as a small protuberance on the ovary wall and then the cells divide continuously to form the ovule core enveloped in an outer coat and in inner coat. In front of the ovule core is a small opening for the pollen tube to enter the ovule core. The base of the ovule core where the ovule coats emerge is called the jointing point. When the paddy rice spikelet differentiates, the ovule core differentiates into a large cell called the embryo sac mother cell (also called megaspore mother cell). The embryo sac mother cell reduces and divides to form four cells (called the embryo quadruplet). In this embryo quadruplet, three of them soon degenerate and only the cell furthermost from the ovule core opening grows into a mononuclear embryo sac (megaspore), thus each ovule has only one embryo sac. This embryo sac absorbed the nutrients in the cells surrounding the ovule core and continues to grow and then undergoes three cell divisions to form eight free nuclei. Of these eight nuclei, three move towards the side of the embryo sac where the ovule core opening is located to form the cell wall and three cells, one of which becomes the synergid cells. Another three nuclei move towards the other side of the embryo sac to form three cells called the antipodal cells. The other two nuclei move to the center of the embryo and fuse together to form a large cell as the central cell (polar nucleus cell). In this way, a mononuclear embryo sac develops into a mature embryo sac (Diagram 45). Formation of monunuclear embryo sac of paddy rice and pollen grain takes place almost simultaneously.

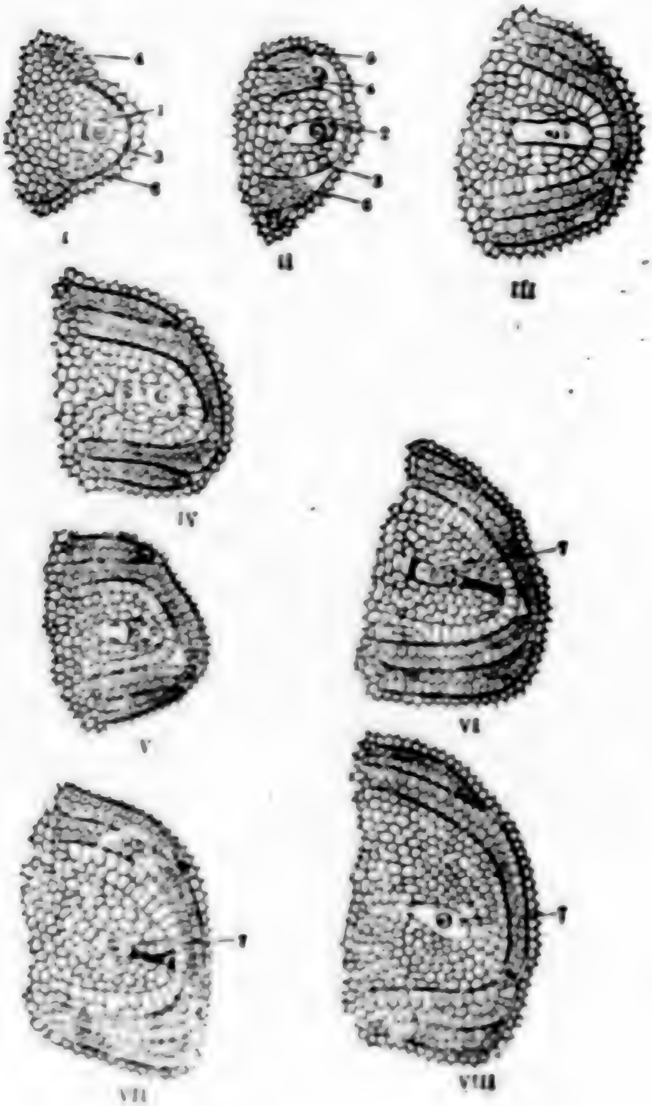
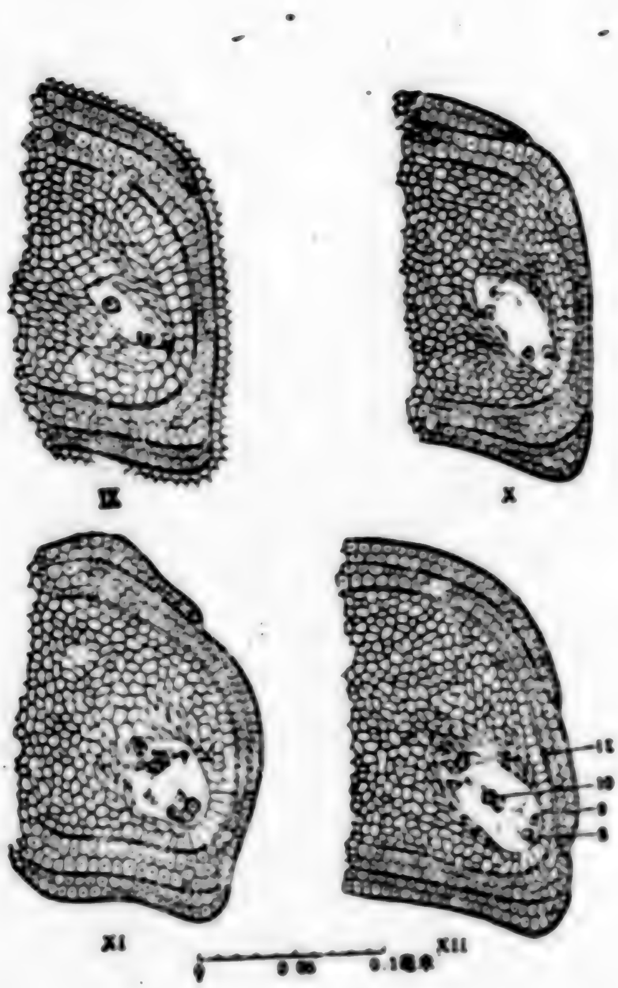
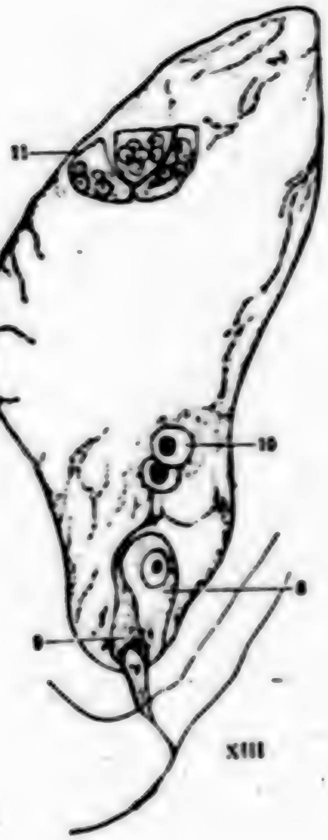


Diagram 45-(1)



0 0.05 0.1 millimeter

Diagram 45. Formation and Development of the Paddy Rice Embryo Sac (Dai Lunyan (2071 0243 3543) et al 1964)



I. Pseudospore primary cell and origin of inner ovule core coat.
1. protospore 3. ovule 4. inner ovule coat 6. ovary wall.
II. Pseudo embryo sac mother cell, inner ovule core coat and outer ovule core coat.
III. Metaphase of first meiosis.
IV. Couplet
V. Anaphase of second meiosis.
VI. Quadruplet. The three cells near the ovule core opening begin to disperse and disappear. The outline of the third cell can still be seen.
7. Embryo sac
VII. The embryo sac is established, the three cells near the ovule core opening disappear.
VIII. The embryo sac grows large as if entering state of pre-division. At this time or slightly before, the ovule core starts moving from its horizontal position downwards.
IX. Two-nuclei embryo sac.
X. Four nuclei embryo sac.
XI. Eight nuclei embryo sac.
XII. Egg-like organ, antipodal organ and polar nucleus.
8. Egg cell 9. Synergid cell
10. Polar nucleus 11. Antipodal cell.
XIII. The mature embryo sac which has clearly grown large. The antipodal cells have moved to the side. The egg cell has also grown large. The polar nucleus is near the egg cell. The synergid cells are shaped like hooks. The ovule core opening seems to be penetrated by a pollen tube.

C. A Simple Method to Determine the Time of Differentiation of the Young Panicle.

Determination of the time when the young panicle differentiates is very important in paddy rice production. On the one hand we can take key measures to produce high and stable yields according to the progress of young

panicle differentiation and on the other hand we can predict the heading and mat ration times according to the progress of young panicle differentiation. Thus, in breeding and seed propagation of hybrid rice this is very imp rtant.

The method to understand the progress of young panicle differentiation is to make direct observations under the bifocal anatomic lens or under the microscope. Certain equipment is required and the method is rather complicated and thus cannot be easily popularized. Therefore, a simple method of determination using outer shape and it relationship to the organs to determine the time of young panicle differentiation is significant in production practices. The most commonly used simple methods of determination are:

1. Leaf age index and leaf age remaind r

A corresponding relationship between the progress of young panicle differentiation of paddy rice and the growth of leaves is relatively stable. Since the leaf age varies with different varieties and conditions of cultivation, the leaf age index and the leaf age remainder are generally used as indicators to determine the time of young panicle differentiation. The leaf age index is the number of leaves already emerged as a percentage of the total number of leaves on the main stem.

$$\text{Leaf age index (\%)} = \frac{\text{Number of leaves already emerged}}{\text{Total number of leaves of main stem}} \times 100$$

For example, when the total number of leaves on the main stem is 10 and the number of leaves already emerged is 6, the leaf age index is 60 percent. When the total number of leaves on the m n stem is 12 and the number of leaves already emerged is 6, the leaf a index is 50 percent. It can be seen that on a main stem when the total number of leaves is different, the same leaf will have a different leaf age index. Thus, the leaf age index can more accurately reflect the progress of development than leaf age. But to understand the leaf age of the moment, the plants in the large fields must be counted and marked and systematically observed. This places a definite limitation of growth and development and having fewer leaves in total on the main stem generally have a low leaf age index. The beginning period of young panicle differentiation is about a leaf age index of 75 percent to 76 percent. The beginning period of young panicle differentiation occurs at a leaf age index of about 78 percent to 79 percent on varieties with a longer growth and development period and a larger total number of leaves on the main stem.

The leaf age remainder indicates the number of leaves which have not yet emerged. This method does not require counting and surveying the plants in the large field. The method is convenient and can be more easily grasped [by the peasants]. The time when the reverse third leaf shows its tip is generally the time when panicle differentiation begins (Table 34).

Table 34. Reverse Leaf Age of Various Stages of Young Panicle Differentiation of Late Rice (Wu Yimin (0702 0001 3046) 1975)

Young panicle differentiation stage	Branch stalk differentiation stage	Spikelet differentiation stage	Meiosis stage	Pollen grain formation and maturing stage
Reverse leaf age	Reverse 3/ beginning to reverse 3/1.0	Reverse 2/ beginning to reverse 2/1.0	Reverse 1/ beginning to reverse 1/0.8	Reverse 1/0.8 to heading

Remark: The flag leaf is counted as the first reverse leaf. The first leaf below it is the reverse second leaf. The second leaf below the flag leaf is the reverse third leaf, and so on. When one leaf has completely extended and shows the leaf ring, it is indicated by "reverse n/1.0." If a leaf has not fully extended, the portion that has extended is expressed by a decimal of the total length of the leaf. For example, when the leaf below the flag leaf has extended halfway, it is represented by "reverse 2/0.5," and so on.

Table 34 shows that the period between the time the reverse third leaf begins to show its point and the time the reverse third leaf has completely extended is exactly the period when the branches of the young panicle are differentiating. The differentiation period of the spikelet lasts through the entire emergence of the reverse second leaf. The period of meiosis occurs within the period of the emergence of the flag leaf, beginning when the flag leaf first emerges (shows point) and ending when the flag leaf has extended 80 percent (within the period of 1/0.8). The period from 1/0.8 to heading (beginning of heading) is the period of pollen formation, filling and maturation.

Since the flag leaf almost achieves complete extension during the period from young panicle differentiation to pollen mother cell meiosis, the use of leaf age index age reminder to indicate progress of young panicle differentiation is only applicable before emiosis.

2. Calculating the Number of Days Prior to Heading or Prior to Young Panicle Differentiation

The beginning period of differentiation of the primordia of the secondary branch is generally 7 days after the young panicles begin to differentiate (i.e., 29 to 25 days prior to heading). The spikelet differentiation period is generally 10 to 14 days after young panicles begin to differentiate (i.e., 24 to 17 days prior to heading). Pollen mother cell meiosis is generally 16 to 28 days after young panicles begin to differentiate (about 19 to 13 days prior to heading). This method is valuable as a reference in regions where all varieties sown throughout the year have a relatively stable period of panicle growth.

3. Determination by the Length of the Young Panicle and the Spikelet

The length of the young panicle is extremely small during the differentiation period of the primordia of the primary branch. It is difficult to measure by anatomic observation of the entire body. When white pubescence (pubescence of bract) appearing at the tip of the apical point of the young stem can be seen by the naked eye, the period of secondary branch differentiation has already begun. When a young panicle is about 1 millimeter long, it is in the spikelet differentiation stage. When the young panicle reaches more than 2 to 3 millimeters in length, it is the differentiation period of the pistil and the stamina. When the young panicle reaches 1.5 millimeter in length and the spikelet is about 2 millimeters long, the formation of pollen mother cells has begun. When the length of the young panicle and the length of the spikelet are both about half the final length, it is the period of meiosis. When the young panicle and spikelet reach their full length, it is the period of filling of the pollen grain.

The relationship between the length of the young panicle and the length of the spikelet and the stages of young panicle differentiation of late season rice is illustrated in Table 35.

Table 35. Stages of Young Panicle Differentiation and the Lengths of the Young Panicle and of the Spikelets (Wu Yimin (0702 0001 3046) 1975)

Stage of young panicle differentiation	Branch stalk differentiation period	Spikelet differentiation period	Meiosis period	Period of formation and maturation of pollen grain
Young panicle length (millimeter)	Not visible by naked eye-1.2	1-15	30-60	50-full length
Length of spikelet (millimeter)	Shape not formed	visible by naked eye --1.5	2-5	5-full length

4. Determination According to Length Between Auricle

The distance between the auricles is also called the auricle distance. It refers to the distance between the auricle of the flag leaf and the auricle of the leaf below. When the flag leaf has not yet completely extended and its auricle is below the auricle of the leaf below, the auricle distance is expressed as a negative number. When the leaf blade of the flag leaf has just extended completely, and its auricle is equal (in length) to the auricle of the leaf below, the auricle distance is zero. When the auricle of the

flag leaf extends beyond the auricle of the leaf below, the auricle distance is expressed as a positive number. Observation of the auricle distance is a method of determining the time of meiosis of paddy rice. Past studies conducted abroad showed that meiosis begins when the auricle distance is -10 centimeters, reaches a peak when the auricle distance is 0 and ends when the auricle distance is +10 centimeters. Ding Ying (0002 4481) et al observed a spikelet at the center of a panicle and determined that the pollen mother cell meiosis of the Guangzhou early rice and late rice occurred when the auricle distance was -3.2 and -1.5 centimers respectively. The Wuhan University's Department of Biology observed that the meiosis of "Guangluai No 4" early rice occurred when the auricle distance was between -3 centimeters and 0 centimeter and meiosis of late rice "Nong hong 73" occurred when the auricle distance was between -7 centimeters and 3 centimeters. The Huazhong Agricultural College observed that meiosis of late season rice "E wan No 3" occurred when the auricle distance was between 0 centimeter and -1 centimeter. The Jiangsu, Taichang County, Yuewang Commune's Agricultural Technology Station observed that the late season rice "Hu xuan 19" and "Gui hua huang" varieties' meiosis began when the auricle distance was between -12 centimeters and 3 centimeters and the peak meiotic period occurred when the auricle distance was between -5 centimeters and 0 centimeter. Analysis of the above showed that none reached +10.

5. Calculating According to the Cumulative Temperature Index

Early rice varieties require a definite cumulative temperature during their entire growth peiod. Each of their growth stages also requires a definite cumulative temperature. The cumulative temperature growth index is the cumulative temperature of a certain growth period expressed as a percentage of the total cumulative temperature of the entire growth period. Observations made by the Shaoxing Field Group of the Zhejiang Academy of Agricultural Science showed when the cumulative temperature for growth index reaches 33.66 percent, it is the beginning stage of young panicle differentiation. When the cumulative temperature for growth index reaches 39.1 percent, it is the secondary branch differentiation period. When the cumulative temperature for growth index reaches between 53 percent and 55 percent, it is the beginning period of meiosis, and when the cumulative temperature for growth reaches 68.1 percent, it is the full heading period.

For actual determination of young panicle differentiation, the above methods should be combined so that more accurate determinations can be made. The main stem should be taken as the main object of observation and the period of differentiation of over 50 percent of the total number of stems should be taken as representative. Since the development of the tillers often lags behind that of the main stem, progress of young panicle differentiation in the large field often lags behind the inspected samples.

The following tables list the physical characteristics of each stages of young panicle differentiation and their indicators of determination (Tables 36-39) compiled by Wu Yimin (0702 0001 3046), the Hubei Huanggang Prefectural Agricultural School Crop Teaching and Research Group and the Central China (Huazhong) Agricultural College as reference.

Table 36. Physical Characteristics of Each Stage of Young Panicle Differentiation (Hubei Huanggang Prefectural Agricultural School, 1975)

(1)	(14)						(22)					
	(15)	(16)	(17)	(18)	(19)	(20)	(15)	(16)	(17)	(18)	(19)	(20)
(2)	3/19						3/19					
(3)	4/21	8.3	44.2				4/19	8.4	46.9			
(4)	5/13	8.6	70.0	0.1~0.2			5/15	9.1	68.9	0.1~0.2		
(5)	5/17	9.1	75.8	0.1~1.0	(21) 0.1		5/19	9.7	73.5	0.1~0.4	(23) 0.1	
(6)	5/21	9.6	80.0	0.1~1.2	0.1~0.2		5/24	10.3	78.0	0.2~1.5	0.1~0.3	
(7)	5/25	10.1	84.2	0.4~1.5	0.4~0.8		5/27	10.7	81.1	0.2~3.5	0.3~0.6	
(8)	5/28	10.5	87.5	1.3~2.5	1.7~4.5	0.1~0.2	5/31	11.2	84.5	0.9~3.6	1.0~7.0	
(9)	5/31	10.9	90.8	0.8~2.3	5~9	0.5~0.8	6/5	12	90.9	2.1~2.6	15~19	0.1~0.3
(10)	6/4	11.4	95.0	0.7~2.4	10~15	0.7~0.9	6/8	12.4	93.9	1.0~2.1	16~19	0.3~0.5
(11)	6/9	12	100.0	0.5~2.0	18~20	0.9~1.0	6/11	12.7	96.2	0.9~2.0	18~20	0.6~0.8
(12)	6/13	12	100.0				6/17	13.1	99.2			
(13)	6/16	12	100.0				6/21	13.2	100.0			

Key:
(1) growth period
(2) sowing time
(3) transplanting time
(4) differentiation of primordium of first bract
(5) differentiation of primary branch
(6) differentiation of primordium of spikelet and secondary branch
(7) formation of pistil and stamina
(8) formation of pollen mother cell
(9) pollen mother cell meiosis
(10) pollen filling
(11) pollen completion
(12) beginning of heading
(13) full heading
(14) Guang lu ai No 4
(15) month/day
(16) leaf age
(17) leaf age index (%)
(18) length of first internode (centimeter)
(19) length of young panicle (centimeter)
(20) length of spikelets (centimeter)
(21) larger than
(22) Long ge No 16
(23) smaller than

Table 37. "Ewan No 3" Young Panicle Differentiation Period's Indicators (Central China (Huazhong) Agricultural College 1975)

(1) 幼穗分化过程	(2) 开始时期(月/日)	(3) 叶龄	(4) 叶龄余数	(5) 叶龄指数(%)	(6) 持续天数	(7) 幼穗长度(厘米)	(8) 距始穗期天数
第一苞分化期 (9)	8/16	11.1	2.9	79	1		29
(10) 一次枝梗原基分化期	8/17	11.3	2.9	81	2		28
二次枝梗原基及颖花分化期 (11)	8/19	11.6	2.4	83	6	0.03~0.1	26
雌雄蕊形成期 (12)	8/25	12.3	1.7	88	6	0.15~0.5	20
花粉母细胞形成期 (13)	8/31	13.1	0.9	94	2	1~2	14
花粉母细胞减数分裂期 (14)	9/2	13.4	0.6	96	2	4~6	12
花粉粒外壳形成期 (15)	9/[illegible]	14.0	0	100	4	10~12	8
花粉粒成熟期 (16)	9/12	14.0	0	100	4~6	13~16	2

Remark: Sowing time was June 24, transplanting time was July 24, heading began on September 14.

Key:
(1) Panicle differentiation process
(2) Beginning time (Month/day)
(3) Leaf age
(4) Leaf age remainder
(5) Leaf age index (%)
(6) Days of continuation
(7) Length of young panicle (centimeter)
(8) Days from beginning of heading
(9) First bract differentiation
(10) Primary branch primordia differentiation
(11) Secondary branch primordia and spikelet differentiation
(12) Formation of pistil and stamina
(13) Formation of pollen mother cell
(14) Meiosis of pollen mother cell
(15) Formation of outer coat of pollen grain
(16) Maturation period of pollen grain

Table 38. Comprehensive Indicators for Observing Seedlings for Diagnosis During Young Panicle Differentiation and Forecasting the Heading Time of Late Season Rice (Wu Yimin (0702 0001 3046) (1975)

幼穗发育阶段 (1)		正在出生的叶片（倒叶龄数）(2)	幼穗长度（毫米）(3)	颖花大小（毫米）(4)	花药大小颜色（毫米）(5)	叶耳距（厘米）(6)	特征 (7)	该阶段持续的天数 (8)	抽穗前的天数 (9)
(10) 幼穗形成期	(11) 枝梗分化期	(12) 倒3/始~倒3/1.0	(13) 肉眼不可辨~1.2	(14) 未成形			1.倒三叶露尖幼穗分化开始。 2.肉眼开始可见生长点有白毛，已是枝梗分化后期。 3.生长点出现一、二次突起。(15)	(16) 早熟晚粳: 4 中粳: 4 (17)	26~29 22~25
	(18) 颖花分化期	倒2/始~倒2/1.0 (12)	1~1.5	肉眼可辨~1.5(颖花分化后期) (19)			1.一般幼穗长达1毫米即为颖花分化期。 2.当幼穗长到5毫米以上为后期，这时颖花完整形态肉眼已可辨。(20)	(16) 早熟晚粳: 6 中粳: 5.5 (17)	20~25 21~17
(21) 孕穗期	减数分裂期 (22)	倒1/始~倒1/0.8 (12)	13~60	2~5	0.2~0.8（白色）(23)	−12~−3（始期）(24) −5~0（盛期）(25)	叶耳距在0之前，花药白色，均处减数分裂期。(26)	早熟晚粳 (16): 4 中粳: 4 (17)	16~19 17~13
	花粉形成期 (27)	倒1/0.8~抽穗 (28)	50~定长 (29)	5~定长(7~8) (30)	0.8~2.0（黄绿色）(31)	−5~抽穗 (32)	花药由白变浅绿再变为黄绿。(33)	早熟晚粳: 16 (16) 中粳: 11.5 (17)	15~抽穗 (34) 12~抽穗

Key: (1) young panicle development stages
(2) emerging leaves (reverse leaf ages)
(3) length of young panicle (centimeter)
(4) length of spikelet (centimeter)
(5) size of anther and color (centimeter)
(6) auricle distance centimeter
(7) characteristics
(8) days of continuation
(9) number of days before heading
(10) young panicle formation period
(11) branch differentiation
(12) reverse _/beginning to reverse _/__.
(13) invisible to naked eye to 1.2
(14) not formed
(15) 1. Reverse third leaf shows tip. Young panicle differentiation begins.
2. The naked eye can see the apical point's white pubescence. Branch differentiation is at latter period.
3. One or two protuberances emerge at apical point.
(16) Early maturing late geng
(17) Intermediate geng
(18) Spikelet differentiation
(19) Visible by naked eye to 1.5 (latter period of spikelet differentiation)

[Key continued]

(20) 1. Ordinary young panicles reach 1 millimeter in length, marking spikelet differentiation period.
2. When young panicle grows to 5 millimeters or above, spikelet differentiation is at latter period. At this time, the spikelet's entire form is visible to the naked eye.

(21) Panicle bearing period
(22) Meiosis (spikelet degeneration period)
(23) (white)
(24) (beginning)
(25) (peak)
(26) Auricle distance is less than 0, another is white. Cells are in meiosis
(27) Formation of pollen and maturity period
(28) Reverse 1/0.8 to heading
(29) 50-full length
(30) full length
(31) (yellowish green)
(32) heading
(33) Anther's color changes from white to light green and to yellowish green
(34) heading

Table 39. Several Methods of Dividing the Panicle Differentiation Period and Their Major Characteristics

Divisions of Young Panicle Development				Major Characteristics
First method	Second method		Simple method	
1. First bract differentiation	1. Panicle axis differentiation period		branch differentiation	First bract's primary body emerges.
2. Primary branch primordia differentiation	2. branch differentiation	(1) primary branch differentiation		Primordium of primary branch emerges at base of panicle primordium and others emerge from bottom to top one after the other
		(2) secondary branch differentiation		Secondary branches' primordia emerge at tip of the primary branch's base and others emerge from bottom to top one after another. The naked eye can see the young panicle covered with white pubescence
3. Secondary branch primordia and spikelet differentiation	3. spikelet differentiation	(1) spikelet differentiation's prophase	spikelet differentiation	The primoria of the rudimentary glume and sterile lemma of the spikelet tip emerge. The young panicle is about 1 millimeter long.
4. Formation of pistil and stamine				The primordia of the lemma and palea of the spikelet of the top emerge followed by the primordia of stamina
		(2) spikelet differentiation's metaphase (3) spikelet differentiation's anaphase		The stamina differentiate into anther and filament. The pistil begins differentiation. The palea and lemma gradually close. The young panicle is about 0.5 to 1 mm.
5. Formation of pollen mother cells	4. Reproductive cell formation		Meiosis	The pollen mother cell is formed. The lengths of the palea and lemma are double the length of the sterile lemmas. The spikelet is 1 to 3 millimeters long. The young panicle is 1.5 to 5 cm long.
6. Meiosis of pollen mother cells	5. Meiosis			The prophase of pollen mother cell meiosis takes place up to the formation of the single to quadruplet cells. The spikelet is 3 to 5 mm long. The young panicle is 5 to 10 cm long.

Table 39 [Continued]

Divisions of Young Panicle Development			Major Characteristics
First method	Second method	Simple method	
7. Pollen completion period	6. Pollen outer coat formation	Pollen grain filling and completion	The pollen megaspore and the outer coat are formed. The pollen tube opening emerges. The anther has not turned yellow. The spikelet increases to 85% of its entire length or has already reached full length. The glume has not turned green. The young panicle gradually reaches full length.
8. Pollen completion period	7. Pollen completion		The pollen forms two microspores to three microspores. They gradually fill up until they reach full maturity. The anther turns to yellow. The spikelet grows to maximum size in length and in width. The glume changes to green.

Remark: This table combines the results of research conducted at various places.

III. Causes that Affect Differentiation of the Young Panicle

Production practices in agriculture tell us that many demands are made upon the rice panicle. Moreover, the fruiting percentage after heading must be high. A panicle which can achieve this is called strong panicle. There are many things which affect the strong panicle, some are internal and others are external.

A. Inner Causes that Affect Healthy Growth of Panicles

1. Accumulation of Organic Substances

Prior to young panicle differentiation, organic substances that accumulate in the base tissue and the apical point of the panicle from the basis for growth of large panicles. Studies by Murakami Kurenitsu (1962) and Li Rong-qian (0448 1369 0578) showed the changes in organic substances in the young panicle or at the apical point at the time of young panicle differentiation. Prior to young panicle differentiation, the soluble sugars in the apical point decrease. This is because of the accumulation of polysaccharides. After young panicle differentiation begins, polysaccharides begin to decompose, and the soluble sugars increase again. While young panicle differentiation is being actively carried out, soluble sugars decrease again. This is because they are now being used up rapidly in protein synthesis and as an energy source (Tables 40, 41).

Table 40. Changes in the Content of Soluble Sugars in the Base Tissues and Apical Point of Paddy Rice at Young Panicle Differentiation (Microgram/200 Apical Meristems or Young Panicles) (Murakami Kurenitsu (2625 0006 1401 0001) (1962)

糖类 (a)	(b) 生长点或幼穗				生长点基部组织 (g)			
	7月8日 分化前6天 (c)	7月11日 分化前3天 (d)	7月14日 (刚分化) (e)	7月17日 分化活跃期 (f)	7月8日 (h)	7月11日 (i)	7月14日 (j)	7月17日 (k)
(l) 葡萄糖	2	2	4	1.5	4	2	3	3
(m) 果糖	4	3	4	1.5		2	4	1.5
(n) 蔗糖	8	3	24	20		22	24	100

Key:
- (a) sugars
- (b) apical point or young panicle
- (c) July 8, 6 days before differentiation
- (d) July 11, 3 days before differentiation
- (e) July 14, differentiation
- (f) July 17, active differentiation
- (g) Apical point base tissue
- (h) July 8
- (i) July 11
- (j) July 14
- (k) July 17
- (l) glucose
- (m) fructose
- (n) sucrose

Table 41. Changes in Polysaccharide Accumulation During the Young Panicle Differentiation of Paddy Rice (Li Kongqian (0448 1369 0578) (1976)

	I	II	II末 (a)	III	IV	V	VI	VII
(b) 自然光照	+	++	++++	+++	+++	++	+++	
(c) 短日照	+	++	++++	+++	+++	++	+++	++++
(d) 不断光照	+	++						

Remark:
- I. Young apical point period.
- II. Apical meristem grows large.
- III. Young panicle differentiation begins
- IV. Branch differentiation
- V. Sterile lemma and spikelet differentiation
- VI. Pistil and stamina differentiation
- VII. Formation of pistil and stamina.

+ minute amount; ++ obvious; +++ more; ++++ most.

Key: (a) end
(b) natural light
(c) short day light
(d) continuous light

This type of physiological change in the young panicle is the same as the metabolism of the plant in which the plant life changes from expansion (when photosynthetic products are used to grow vegetative organs to expand the plant's physical form) to the accumulation of nutrients. This physiological change causes photosynthetic products to be stored in the stems and the leaf sheaths for continuous supply to satisfy the developmental needs of the young panicle. We had also observed in our past work that prior to young panicle differentiation, starch accumulates visibly in the node of the stem at the bottom of the apical meristem (Diagram 46).

Key: (a) starch
(b) leaf sheath
(c) young leaf
(d) apical meristem
(e) starch accumulated in the node of the stem
(f) accumulation of starch

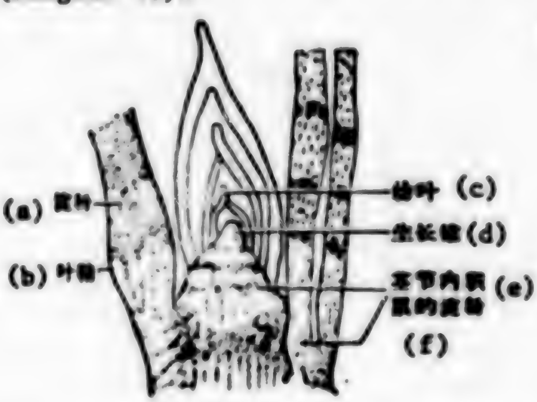


Diagram 46. Prior to young panicle differentiation in the node of the stem near the apical meristem and the leaf sheath (Starch is dyed light blue by KI, illustrated in diagram by black dots)

2. Normal Changes During Growth

It has been mentioned previously that vegetative growth of the paddy rice progresses to a certain stage and the apical point then emerges for the differentiation of leaves and panicles. What are the major causes that bring about such a physiological change?

We learn from production that paddy rice under high temperatures and short daylight will shorten its growth period, head earlier and mature earlier. This shortening of growth happens during the vegetative growth period. Experiments show that when geng rice originally grown in Zhejiang is subjected to 18 hours of sunlight a day, its young panicles will not differentiate and head. Early xian varieties when placed under lower temperatures will prolong their growth period. Thus it can be seen that paddy rice originally grown in high temperatures and short daylight (late rice) reacts to these conditions in a certain way. These reactions are the temperature sensitivity and photoperiodism of paddy rice.

Since research reveals that leaves of paddy rice at a leaf age of 4 to 5 leaves can be stimulated by short sunshine (under suitable temperatures for 5 to 10 short days) or temperature. A certain physiologically active substance (some people call it "florigen") is transported to the apical point and cause the apical point to differentiate into a panicle.

The normality or abnormality of this change in growth greatly affects the healthiness of the panicle. If the early rice seedling is overaged, it may be stimulated by external light and temperatures soon after transplanting and may begin panicle differentiation. Because few leaves emerge between the time of transplanting and differentiation, little organic substances are accumulated. Since the nutritional condition is poor, young panicle differentiation is affected, resulting in the formation of small panicles (Table 42). This is the physiological reason why overaged seedlings produce small panicle heads and cause the yield to reduce. Analysis shows when the seedling of early rice is over aged by one day, the number of leaves emerging after transplanting will be less by 0.22 and the total number of grains will be less by 2.2. A negative correlation exists.

B. External Causes that Affect Differentiation of the Young Panicle

1. Light

During young panicle differentiation, light affects young panicle differentiation mainly by the intensity of photosynthesis it creates. In the field, the intensity of light is abundant. The more light there is the more beneficial it will be to young panicle differentiation and growth. Experiments conducted by concerned units show if light is insufficient during branch and spikelet differentiation, the number of branches and spikelets will be reduced. An insufficiency of light during meiosis and pollen filling periods

Table 42. Effect of Different Seedling Ages Upon Shape of Panicle (Jiangsu Wusi Rice and Wheat Planting Farm 1973)

(a) (天)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
30	40.5	57.7	64.	1076	12	4.8	3.0
35	40.0	70.0	57.6	944	11	5.3	1.9
40	39.3	61.6	47.5	764	11	5.8	1.4
45	38.4	49.3	34.7	546	9.8	6.3	0.2

Remark: Tested variety: "Erfuzao"

Key:
(a) seedling age (day)
(b) number of panicles per mu
(c) number of spikelets per panicle
(d) number of filled grains per panicle
(e) yield (jin/mu)
(f) total number of leaves
(g) leaf age at transplanting
(h) number of leaves emerging between transplanting and differentiation

will cause large numbers of branches and spikelets to degenerate and increase the number of sterile spikelets, thus reducing the total number of spikelets (Table 43). Since meiosis is also the growth period of spikelets, a deficiency of light (shade) will also cause the capacity of the grain to lessen and a reduction in the weight of grains. The effect of increasing the intensity of light and the duration of sunshine is mainly manifested in heightened photosynthetic efficiency and intensity and the satisfaction of the need for organic nutrients by young panicle differentiation. During the growth of the panicle, overly early closing of the rows and overly dense growth in the colony or lengthy dampness and rain are unfavorable to young panicle differentiation. In production practice, whether it is early, intermediate or late rice, closing of the rows should not occur during the beginning of panicle differentiation. Closing of the rows should be controlled so that it will occur 7 to 10 days after young panicle differentiation, i.e., after the flag leaf shows its point so that strong plants and large panicles will be possible.

Table 43. Effect of Light Intensity Upon Young Panicle Differentiation of Paddy Rice

Light intensity	Number of primary branches	Number of secondary branches	Number of spikelets
Natural light	7.3	9.4	65.6
Shaded by two layers of cloth nets	5.9	5.1	46.3

2. Temperature

The most suitable temperature for young panicle differentiation is between 26°C and 30°C. Studies indicate a daytime temperature of 35°C and nighttime temperature of 25°C are most favorable to formation of large panicles. But appropriately lowering the temperatures during the process of young panicle differentiation (not lower than 21°C for xian rice, not lower than 19°C for geng rice) can prolong the branch differentiation period and the time of spikelet differentiation, thus inreasing the number of branches and spikelets. Therefore, timely and early sowing of early and intermediate rice will enable young panicles to differentiate under correspondingly lower temperatures which benefit the formation of large panicles.

Temperatures lower than 21°C for xian rice and lower than 19°C for geng rice will be unfavorable to young panicle differentiation and development. Studies in recent years indicate the period during the process of young panicle differentiation that is most sensitive to low temperatures is 2 to 3 days after meiosis, i.e., the period of development of the pollen quadruplet and the microspore. If temperatures below 17°C occur during this period, the normal development of pollen will be affected. Temperatures below 15°C occurring during this period will seriously affect development of pollen grains and cause male sterility and reduce the fruiting percentage. Damage to young panicle differentiation due to low temperatures during the period of meiosis can be prevented on reduced by irrigating with a deep water layer of 8 to 10 centimeters during the night to raise the temperature of the panicles.

The highest temperature for young panicle differentiation is between 40°C and 42°C. High temperature damage to young panicle differentiation also occurs during the period of meiosis. The first to be damaged are the male reproductive organs, causing large number of spikelets to degenerate and become sterile. Damage to geng rice is more serious than damage to xian rice. Timely sowing, selection of superior seeds and the use of irrigation to regulate temperature (irrigate during the day and drain at night to reduce temperature) will prevent heat damage.

3. Nitrogenous nutrients

Young panicle differentiation and development require consumption of large amounts of nutrients since many new organs are formed at the same time. A good supply of nutrients from the soil (nitrogen, phosphorus, potassium supplies) will enable the young panicles to develop well, reduce degeneration of branches and spikelets, increase the number of grains per mu and stimulate synthesis and transportation of organic substances and the production of photosynthetic products so that many grains and large panicles are formed. Of the nutrients of the soil, nitrogenous nutrients affect young panicle differentiation most visibly. This is because nitrogen is directly related to cell division and enlargement and the synthesis of protein and nucleic acid. Observations made in experiments prove that if the nitrogen content of the paddy rice during young panicle differentiation is deficient and the content of protein and nucleic acid is deficient, then the panicles will be small and the capacity of the grain hulls will be small.

Wu Guangnan [0702 0342 0583] (1962) and Matsushima (1959) shoed by experiment that application of instantly effective nitrogen fertilizers during young panicle differentiation can visibly increase the number of secondary branches and spikelets (Table 44, Diagram 47). Thus the fertilizers applied at this period are called "flower stimulating fertilizer." But according to the simultaneous extension of the organs, application of nitrogen fertilizers at this time will cause the leaves of the upper and middle parts of the plant to lengthen and the internodes at the base of the plant to over extend. Particularly in fields where the development of the colony is too prosperous, this will cause overly dense growth and even lodging. At the same time, differentiation of spikelets will be too abundant and because of a limited supply of nutrients, the spikelets will not develop well, thus causing an increase in the number of degenerate spikelets and in the percentage of empty and semi-filled grains. This defeats the efforts to increase yield.

Experiments also show application of nitrogen fertilizers at the beginning of young panicle differentiation is unfavorable to growth of the palea and lemma of the spikelets because the nutrients are being consumed by the growth of the stems and leaves, affecting the increase in the capacity of the grain. Thus this is unfavorable to increasing the 1,000 grain weight during the latter period. (Diagram 47).

Table 44. Effect of Sidedressing of Nitrogen at Different Periods Upon Development of the Paddy Rice Panicle

处 (1) 理	每穗一次枝梗数 (2)	每穗二次枝梗数 (3)	每穗颖花数 (4)	每穗颖花退化数 (5)	每穗长成颖花数 (6)
对照(不施) (7)	6.6	11.3	75.7	7	68.7
分化前三天 (8)	7.5	16.5	108.5	11.0	97.5
分化后一天 (9)	6.9	15.0	93.2	8.8	84.4
分化后十天 (10)	6.9	12.1	81.9	5.6	76.3
分化后十八天 (减数分裂后期) (11)	7	11	86.6	12.9	73.7

Remark: Variety "Guihuaqui", data in table shows results of analysis of panicles on main stem

Key:
(1) treatment
(2) number of primary branches per panicle
(3) number of secondary branches per panicle
(4) number of spikelets per panicle
(5) number of generate spikelets per panicle
(6) number of mature spikelets per panicle
(7) comparison (not fertilized)
(8) 3 days prior to differentiation
(9) __ day(s) after differentiation
(10) 18 days after differentiation (latter period of meiosis)

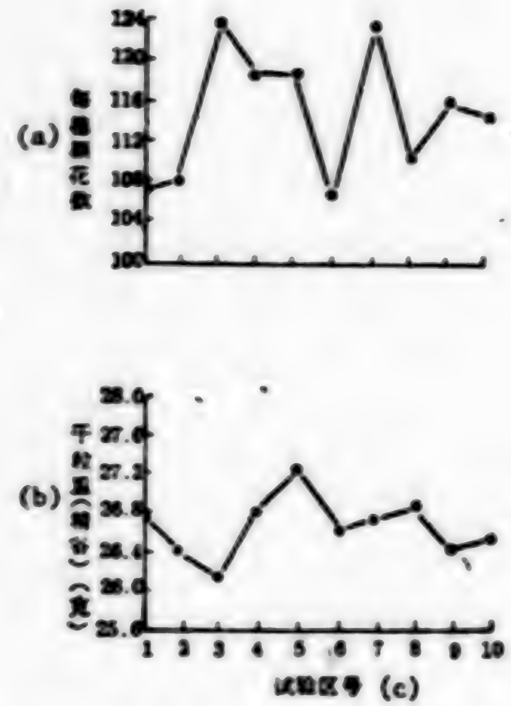


Diagram 47. Effect of Sidedressing of Nitrogen Fertilizers During Various Growth Stages Upon Number of Spikelets per Panicle and 1000 Grain Weight.

Remark: (1) The first experimental region is the comparison (sidedressing was not applied; the 3 region was the first bract differentiation region; the 5 region was of plants prior to meiosis; the 6 region was of plants slightly after heading.

(2) Experimental field's amount of base manure applied was 20.68 jin of ammonium sulphate per mu.

Key: (a) number of spikelets per panicle
(b) 1000-grain weight (fine grain) (gram)
(c) Experimental Regions

Experimental analysis and comparison show application of an appropriate amount of nitrogen fertilizer slightly prior to meiosis can increase the number of spikelets (the effect is a reduction of the number of degenerate spikelets) and also increase the capacity of the grain hull, thus retaining more grains and more spikelets. Hence, this fertilizer is also called the panicle fertilizer or spikelet fertilizer. Spikelet fertilizer applied where the original nitrogen level is not high will visibly increase yield.

4. Moisture

During the time between the beginning of young panicle differentiation and heading, the plant's photosynthesis intensifies. Metabolism is active and

the external temperature is high at this time and amount of evaporation from the surface of the leaves is large. The amount of evaporation of moisture at this time constitutes about 25% to 30% of the total amount of evaporation throughout the entire growth period. Thus this is the period in which the paddy rice plant's physiological need for water is the greatest during the entire life of the paddy rice plant. At the same time a water layer in the paddy rice field facilitates the supply of nitrogen and phosphorus to the plant through the soil. Thus, a deficiency of water during this period will affect the synthesis and transportation of organic matter, affect the development of the branches and spikelets and increase spikelet degeneration and sterility. The adverse effects are felt the most during pollen mother cell meiosis. If the soil becomes dry and arid during this period, large numbers of sterile spikelets and degenerate spikelets will be produced, often reducing yield seriously. During the period of young panicle differentiation, the content of water in the soil constituting above 90% of the soil's maximum amount of water retention will satisfy the paddy rice plant's demand for water. In general, a shallow layer of irrigated water will be appropriate. Sometimes the field can be temporarily irrigated by a deep water layer to retain or reduce temperatures. Some low, wet fields that have poor drainage can be treated with the damp irrigation method to solve the problem of the soil's insufficiency of oxygen. If during the young panicle differentiation period the field is under water for a long period, deformed spikelets will easily be produced. At the same time due to poor aeration, the activity of the root system may be hampered or the roots may blacken, affecting development of the young panicles. Then the panicles will become small. Especially during the period of meiosis and afterwards, if the field is flooded and the "bracts are suffocated," damage will be serious and if the condition lasts for more than 3 days, the entire crop may be lost.

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CHAPTER 5. FORMATION AND MATURITY OF THE GRAIN

After the paddy rice panicle has formed, reproductive growth takes the lead. After heading, flowering, fertilization and filling, the seed is formed. During this period, the root system absorbs a lot of moisture, nutrients. Photosynthesis in the leaves also takes place intensively to manufacture such organic substances as carbohydrates. Organic substances stored in the stems and leaf sheaths undergo decomposition and are transported to the panicles. The amount of these substances (especially products of photosynthesis), the direction of their transportation, and external factors that affect physiological processes in the formation of the grain and maturity determine the percentage of fruiting and the weight of the grains which in turn determine the yield of paddy rice. In cultivation, a series of measures is undertaken to nourish the root and preserve the leaves in order to increase the number of filled grains per panicle and the 1,000 grain weight. The increase and decrease in the number of filled grain and empty or semifilled grains are inversely related processes that determine the yield of paddy rice after the number of panicles and the shape of the panicle have been basically determined. Thus, it is necessary to understand the basic patterns of heading, flowering, fertilization and development of the grain and to analyze the causes of empty and semi-filled grains in paddy rice so that corresponding measures in the techniques of cultivation can be taken to increase the number of filled grains and weight of grains which bring about high yields.

I. Heading and Flowering

A. Heading

After the young panicles have differentiated and completely developed, the upper internodes of the rice panicle rapidly elongate and emerge from the leaf sheath of the flag leaf. This process is called heading.

The order of heading of the rice plant generally begins from the main panicle on the main stem followed by the order of tillering and emergence of the panicles tillers.

The duration from the beginning of panicle emergence to full heading (5 days for early rice, 7 to 10 days for late season rice) can be taken as an indicator of the uniformity of heading. Uniformity of heading of panicles

varies among different varieties and is related to cultivation management, growth conditions of the plant and the weather at the time. If heading is not uniform, the field will be difficult to manage and maturity will not be uniform, thus affecting the quality and yield of paddy rice. In production, besides selecting varieties that head uniformly, field management in the previous [cropping] period should be carefully considered so that the plants will grow strongly, healthily and uniformly.

B. Flowering

Prior to the flowering of paddy rice, the palea and lemma are closely clasped together. The anther is located in the middle and bottom parts of the spikelet. When flowering occurs, the large amounts of starch stored in the scales (cuticles) rapidly hydrolyze to become soluble sugars. The scales absorb moisture and expand threefold. The rapid extension of the filaments creates pressure that pushes the lemma downward and outward at a 30° angle. It takes 13 minutes for the palea and lemma to open up fully. At flowering, the changes in the elastic structure of the inner wall of the anther and the extension of filaments cause the anther to burst and the pollen to fall on top of the feather-like stigmata of the pistil. This is pollination. After pollination, the scales are stimulated, lose their moisture content and shrink, pulling the palea and lemma to close and clasp together (Diagram 47). Under the most suitable temperatures and humidity, duration from the opening of the palea and lemma to closing varies with varieties and conditions but is generally 1 to 2 hours. Observations made by the Shanghai University Biology Department indicate the duration from opening to closing of the palea and lemma of early xian "Erjiuqing" and "Ainanzao No 39" is 55.5 ± 6.25 minutes and 55.6 ± 9.7 minutes respectively and that of late geng "Jia nong No 14" is 44.23 ± 10.7 minutes.

Under normal conditions, flowering occurs the same day when the spikelet at the tip of the early rice panicle emerges from the leaf sheath but flowering occurs generally on the next day after heading for late rice. Observations show flowering of early rice is concentrated on the day of heading and the second day with flowering occurring the most abundantly on the second day after heading. Each panicle requires 4 to 5 days to complete flowering. Flowering of late season rice is concentrated within the second to the fourth days after heading, with flowering most abundantly on the second and the third days. Each panicle requires 6 to 7 days to complete flowering.

The order of flowering of the paddy rice plant begins with the panicles on the main stem followed by the first tiller panicle, the second tiller panicle... The order of flowering on the single panicle begins with the spikelets at the top of the branch at the top of the panicle, followed by the simultaneous flowering of the spikelets at the base of the upper branch and the spikelets on the middle branch, then followed by the flowering of the spikelets at the base of the middle branch and the spikelets at the tip of the bottom branch. Flowering of the spikelets at the base of the bottom branch occurs last. The order of flowering on each branch generally is

',6,5,4,3,2, (from the tip numbered downward), or 1,3,2. The second flowering occurs 1 to 2 days later than all other flowering since early rice flowering is concentrated, 80 percent of the florets flower within 2 days, this pattern is not obvious but the pattern is obvious in late season rice (See Diagram 48, 49)). Generally the florets that flower first are called strong florets and those that flower late are called weak florets. Weak florets often form immature rice, poor quality rice and semi-filled rice because of insufficient filling or empty grains because of lack of fertilization.

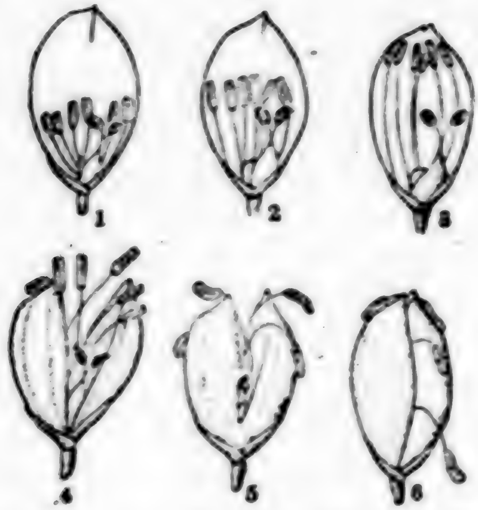


Diagram 47. Flowering Process of the Paddy Rice Plant (Numbers List the Order of Flowering)

The time of flowering within a day has been observed by the Shanghai Teacher's University's Biology Department. The flowering time of early rice occurs early, generally from 0800 hours in the morning to 1400 hours in the afternoon. Flowering peaks between 9:00 and 11:30 in the morning and lessens after 12 noon. Flowering time of late season rice begins at 9 o'clock in the morning. Flowering is concentrated between 10 and 12 in the morning with a peak flowering time occurring at about 11 o'clock in the morning. This is one hour later than flowering of early xian rice. Farm chemicals should not be sprayed near the peak flowering time to avoid affecting normal flowering and fertilization.

Of all the external conditions affecting flowering, temperature is the most important factor. The most suitable temperature for flowering is 30°C, the highest temperature is 50°C [sic] and the lowest temperature is 15°C. Early or late occurrence of flowering time and peak flowering time is related to temperature. When the weather is clear and sunny and the temperature is high, flowering occurs correspondingly early and vice versa. If the temperature fluctuates, double peaking often occurs (Diagram 50, 51). If the temperature is below 20°C, the flowering time will be delayed. Observation

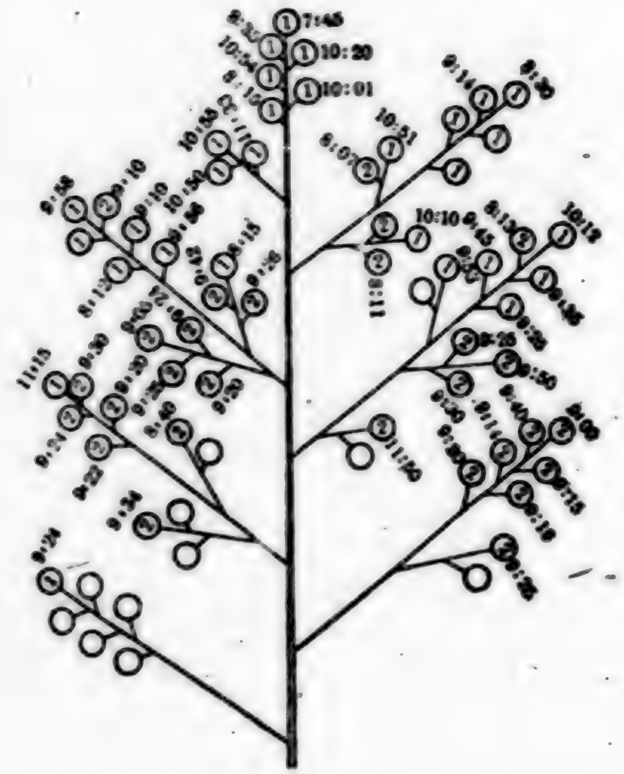


Diagram 48. Early Rice "Ainanzao No 39" Flowering Order (Shanghai Teacher's University, Biology Department, 1975) (Numbers on the spikelets indicate the day after heading when flowering occurs, the numbers beside the spikelets indicate time of flowering)

by the Shanghai Botanical Physiology Institute indicates a temperature of 20°C will delay the flowering time of late season rice by one day and its flowering peak will be delayed by 2 to 3 days. Under a temperature of 17.5°C, its flowering time will be delayed by 2 to 4 days and the cycle of flowering days will not be obvious. After 5 days under such temperatures, flowering will drop to 4.6 percent to 19.2 percent and dispersion of pollen by the anther will be poor. Flowering will be abundant after the plant is moved to normal temperatures. Under temperatures of from 12.5°C to 15°C, flowering time will be delayed by 4 to 5 days. After the 5th day, flowering will drop to only 0.2 percent to 1.1 percent but the anther cannot shed pollen. After moving the plant to normal temperatures, a large amount of flowering is still possible. It can thus be seen that cessation of flowering is a protective reaction of paddy rice against low temperatures. But when low temperatures persist for over 3 days, although there is a cessation in flowering, flowering is still possible after the plant is placed under normal temperatures but the fruiting percentage clearly is reduced.

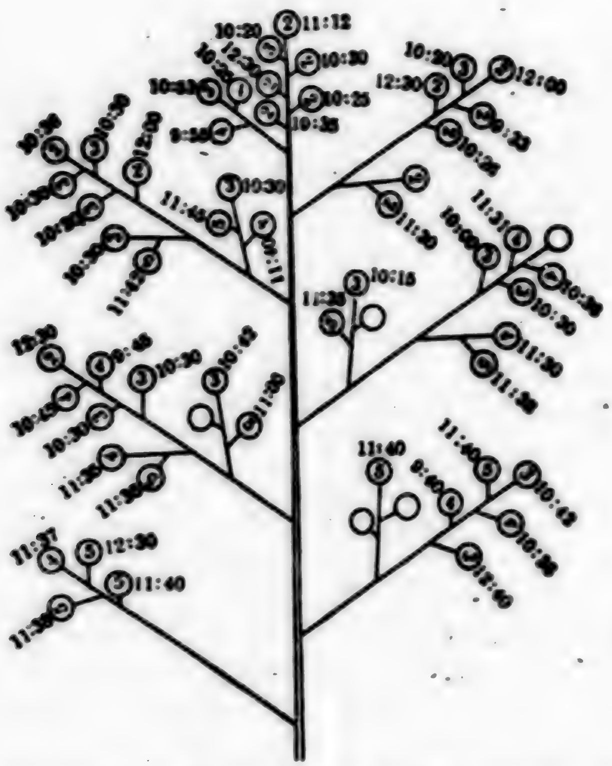


Diagram 49. Late Season Rice "Jianong No 14" Flowering Order (Numbers on Spikelets indicate the day after heading, the numbers beside the spikelets show time of flowering)

Key: (a) number of flowers (floret)

(b) temperature °C

(c) time of day (hour)

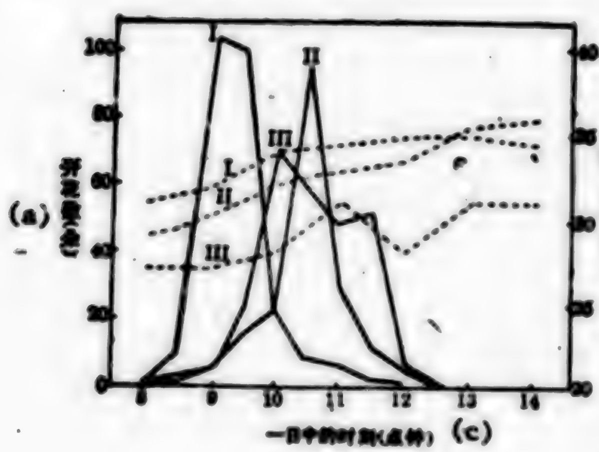


Diagram 50. Relationship Between Temperature and Flowering Activity of the Panicle of Early Rice "Ainanzao No 39" in a day (I: July 10, LL. July 11, III. July 12)

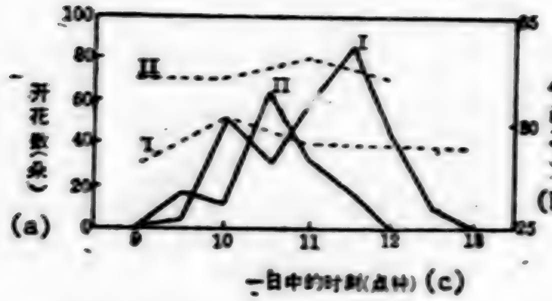


Diagram 51. Relationship Between Temperature and Flowering Activity of the Panicle of Late Season Rice "Jianong No 14" in a Day (I. September 17, II. September 19)

Key: (a) Number of flowers (floret)
(b) Temperature °C
(c) Time of day (hour)

C. Pollination and Fertilization Processes

1. Pollination

Paddy rice is a self-pollinated crop with a natural hybridization rate of below 1 percent. At flowering, the anther bursts and pollen sticks of the stigmata at the same position as the anther. At the same time the filaments extend rapidly and rub against the palea and lemma, stimulating the anther to burst open and shed pollen. But, under particular conditions when the weather is poor during flowering time, pollination occurs even though the palea and lemma do not open up (i.e., closed glume pollination) or the palea and lemma will open for a long time but the anther will not burst open. This indicates that the bursting of the anther and flowering are not necessarily related. However, bursting of the anther is an important condition to assure pollination and fertilization. Internal and external conditions that are unfavorable to bursting of the anther and pollination also constitute reasons for poor pollination and increases in empty grains.

2. Germination of the pollen and growth of the pollen tube

The pollen contains a rich storage of substances. Analysis indicates the pollen of the paddy rice contains the following major contents:

moisture	6.88%
ether extract	3.42%
reduced sugar	14.11%
sucrose	25.18%
protein	20.69%
starch	9.66%
crude fiber	3.74%
other carbohydrates	13.12%
ash (inorganic salts)	3.2%

In addition, the pollen also contains many kinds of enzymes and plant hormones.

Studies indicate the chemical composition of the pollen on hybrid rice and its three lines are extremely dissimilar (Table 45).

Table 45. Differences in Chemical Composition of Pollen of Hybrid Rice and Its Three Lines (Shanghai Plant Physiology Institute, 1977)

Variety	Starch (μg/100 anthers)	Protein (μg/100 anthers)	Glutamic acid mg/100 mg amino acid)	Asparagine (mg/100 mg amino acid
Erjiunan No 1 (A) (sterile)	0	200	5.6	59.2
Erjiunan No 1 (B) (sterile free)	206.6	832	27.8	8.3
IR-661 (Restorer)	290.6	2190	32.7	7.6
Nanyou No 3 (hybrid)	317.7	1420	34.6	8.8

Table 45 shows the content of starch and protein of the pollen of the sterile line is especially low. This is related to its male sterility. The content of starch in the hybrid rice is especially high, indicating the characteristic of strong vitality of the pollen. Another characteristic is the low content of glutamic acid in the pollen of the sterile line and the high content of asparagine while the content of glutamic acid in the pollen of hybrid rice is relatively high. Based on studies, it is believed glutamic acid stores the amino acid stored the amino acids in pollen and is related to the metabolic activity of pollen germination and growth of the pollen tube.

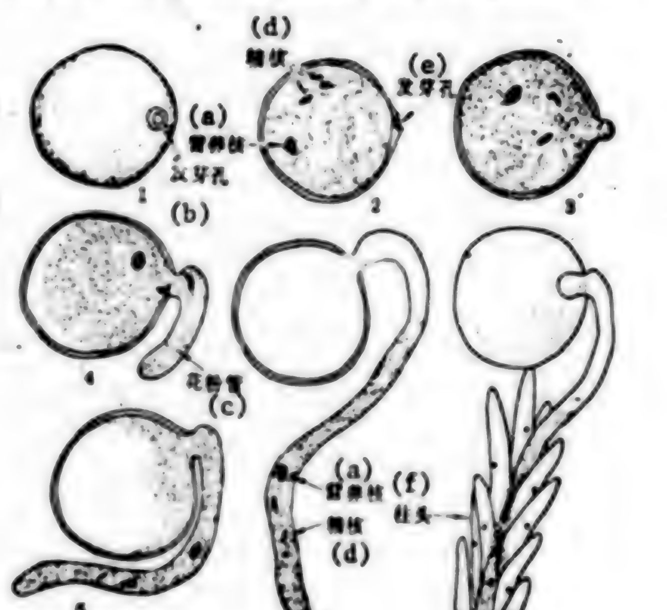
When pollen falls on the stigma it is stimulated by the secretion of the stigma, absorbs the secretion of the stigma and also secrets its own substance into the stigma at the same time. Through this mutual exchange, the pollen grain expands internally. The inner wall emerges through the germination opening and extends to form the pollen tube (Diagram 52). The germination process of the paddy rice pollen is fast, beginning 1 to 2 minutes after pollination.

The conditions for pollen germination include both external and internal conditions. Normality of the pollen grain must be coupled with certain physical and chemical conditions of the stigma. Of these conditions, water, sucrose, certain osmotic pressure and pH value are important. These conditions also include certain inorganic salts, organic acids and amino acids and suitable temperature (30°C).

The ability of the stigma to be fertilized is the highest on the day of flowering. The ability gradually reduces and finally is lost three days after flowering. The pollen grain's ability to fertilize also reduces rap'dly after rupture of the anther. Experiments show the ability to be fertilize drops 5 percent within the first five minutes. Thus the functioning period of the pollen and the stigma is very short under normal conditions. Thus in production, especially in sexual hybridization and cultivation and seed propagation of hybrid rice, this should be taken into consideration.

The spikelet's stigma secretes a glutinous secretion and plant hormones. The nipple on the stigma easily attracts pollen and the pollen that has fallen on the stigma rapidly germinates and forms the pollen tube. The tip of the pollen tube secretes pectase that dissolves pectin. The enzyme also stimulates extension of the pollen tube. Some 1.4 to 3.0 minutes after the pollen falls onto the stigma, the pollen tube begins to extend. After 5 minutes the pollen tube reaches a length equal to the diameter of the pollen. As the pollen tube extends, the content of the pollen enters the pollen tube. Half an hour after flowering and pollination, the pollen tube, relying upon the physiological differences of the style from the stigma to the ovary and upon the secretion of amylase to decompose and absorb the nutrients in the style, grows in a definite direction until the ovule core opening is reached. During the process of growth of the pollen tube, the pistil excretes boron which is important to the germination of the pollen and the growth of the pollen tube. Boron forms polymers with sugars thus stimulating absorption, transportation and metabolism of sugar to participate in the building of the wall of the pollen tube. Thus in production, boron is often sprayed around the roots to stimulate the extension of the pollen tube, fertilization and fruiting.

Key: (a) vegetative nucleus
(b) opening for germination
(c) pollen tube
(d) sperm
(e) opening for germinating
(f) stigma



1. Outer shape
2. Anatomical diagram
3-7. Germination and extension of the pollen tube into the stigma

Diagram 52. Germination of the Paddy Rice Pollen and Extension of Pollen Tube into the Stigma (Hoshigawa Kiyoshin 2502 1557 3237 6024), (1975)

3. Fertilization

The Cytology Research Laboratory of the Botany Institute of the Chinese Academy of Sciences (1965) and Chen Meisheng (7115 2734 3932) (1974) of the Biology Department of the Hunan Normal College observed in detail the process of fertilization in some varieties described below:

Between 0.5 and 1 hour after flowing, the pollen tube reaches the ovule core opening and releases the contents of the pollen into the embryo sac (containing a pair of sperms). After the contents of the pollen have entered the embryo sac and as they increase, they begin to move towards the egg cell from in between the egg cell and the synergid cell, then towards the tip of the egg cell along the surface of the egg cell and finally joint the synergid cell to form a bract coat covering the egg cell from one side to the other (appearing like the horns of the water buffalo when observed from a longtiduinal cross section).

About 1.5 hours after flowering, a sperm and the egg cell come into contact and the sperm enters the egg cell and approaches the egg nucleus and attaches itself to the nuclear membrane of the egg. Two hours after flowering, the sperm enters the egg nucleus and begins to loosen up, disperse and fuse. A small male nucleolus appears and then enlarges to about the same size as the nucleolus of the egg cell (about 6 to 7 hours after flowering). The male and the female nucleoli fuse together, indicating the completion of the process of fertilization of the egg cell. The egg cell that has been fertilized is called the fertilized egg which develops to become the embryo (Diagram 53).

Another sperm in the meantime comes into contact with one of the polar nuclei and enters that nucleus, disperses and fuses. A male nucleolus emerges. Between 2.5 to 3 hours after flowering, the male nucleolus and the polar nucleolus fuse and then the fusion nucleus fuses with another polar nucleus (called the triple nuclei fusion) to form the endosperm nucleus. This indicates the completion of fertilization of the polar nuclei. It can be seen that this process of fertilization is similar to the process of fertilization of the egg cell, only faster.

The above shows fertilization of paddy rice includes fertilization of the egg by the sperm and fertilization of the polar nuclei by the sperm, therefore it is called double fertilization. Double fertilization is a common characteristic of angiosperms. This is very significant in biology. The characteristic of double fertilization is mainly manifested in the formation and characteristics of the endosperm. One sperm fuses with two nuclei to form the triploid endosperm nucleus. From this is produced the endosperm which includes the genetic characteristics of both parents and is thus more suitable as the nutritive substance for the development of the embryo.

In addition, many pollen tubes were observed moving towards the embryo sac during the process of fertilization of paddy rice and a lot of the contents of the pollen tubes participated in the process of fertilization. Not only two and three sperms were observed entering the egg but during the process

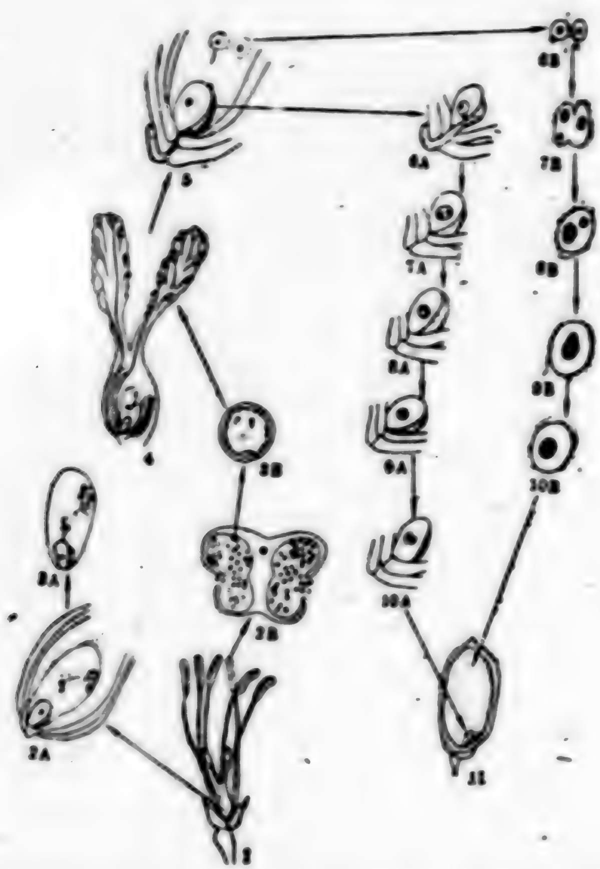


Diagram 53. Fertilization process of paddy rice (Illustrated from photos provided the Hunan Teacher's College, Biology Department)

1. Pistil and stamina. 2A. Cross section of ovule showing embryo on the ovule stamina. 2B. Cross section of anther showing pollen inside pollen sac. 3A. Mature embryo showing egg cell, polar nuclei and antipodal cell. 3B. Mature pollen grain showing two sperms and a vegetative nucleus. 4. Pollination showing pollen grain falling on top of stigma, developing and entering embryo. 5. Double fertilization process begins with two sperms entering the embryo, one contacts the egg cell and the other advances towards the polar nucleus. On the side of the egg cell the pollen tube's contents form a hook shaped structure and envelop the egg cell's surface. 6A. The sperm has entered the egg cell and is penetrating the nucleus of the egg. 6B. The sperm is entering one polar nucleus. 7A. The male nucleolus has entered the egg nucleus and begins to grow large. 7B. The male nucleolus grows in one polar nucleus. The polar nucleus develops a cell plate and begins to dissolve. 8A. The female and male nucleoli are now equal in size and are gradually approaching each other. 8B. A male nucleus has fused with one polar nucleus. The fusing nucleolus increases in size. The cell plate between the two polar nuclei has dissolved. 9A. Female and male nucleoli are fusing. 9B. The fertilized polar nucleus' fused nucleolus is combining with

the nucleolus of the other polar nucleus. 10A. The fertilized egg is formed and fertilization is complete. The fertilized egg undergoes a series of division to form the embryo. 10B. The newly formed nucleus of the endosperm is formed and fertilization is complete. The newly formed endosperm forms the endosperm through many cell divisions. 11. The mature caryopsis with the part of the rice grain containing the embryo and the endosperm.

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of fertilization, the contents of many pollen tubes continuously entered the embryo sac and accumulated to the side of the egg cell until the zygote developed into the primordium of the embryo. Then the accumulation of the substances gradually disappeared. This is probably because these substances participate in the formation of the primordium of the embryo. Thus during the process of pollination, it is important to fertilization and fruiting to assure that a certain amount of pollen fall upon the stigata and that the pollen germinate (especially in sexual hybridization and cultivation).

The function of the synergid cells and the antipodal cells in fertilization is not yet clearly understood. Synergid cells may be related to the process of fertilization (their content may provide the nutrients for the egg cell) and the antipodal cells may serve to manufacture nutrients by absorbing nutrients from the ovule core tissue and then manufacturing the nutrients for the embryo and endosperm and the double fertilization process by their own metabolic activity.

II. Formation and Maturation of the Seed Grain

After flowering, pollination and fertilization of paddy rice, the ovule develops to become the seed and the ovary develops to become the fruit. Since the seed coat and the pericarp of paddy rice cannot be separated, the fruit of paddy rice is called a caryopsis or generally called coarse rice or rice grain. The rice grain includes the embryo, endosperm and the seed's true coat (the combined coat consisting of the seed coat and the pericarp). The following will answer the questions: concerning how the embryo and the endosperm are formed and how seed grains reach maturity.

A. Growth of the Embryo and Endosperm

Observations indicate the process of development of the paddy rice embryo is as illustrated in Diagram 54. The fertilized egg undergoes its first cell division 8 to 10 hours after flowering to form an embryo primordium with two cells (the young embryo prior to differentiating into the embryo body and the embryo suspensor is called the embryo primordium). One day after flowering, the cells continue to divide and the number of cells increases to 4 or 6. Two days after flowering, the number of cells increases and the embryo primordium appears pear-shaped. Four days after flowering, the embryo primordium is even larger and differentiation of the outer shape takes place. A lip shaped protuberance emerges on the outside of the embryo primordium (Under a

longitudinal cross section the shape looks like a hook). This is the primordial body of the plumule sheath of the embryo. This lip shaped protuberance begins to extend downward on both sides from top to bottom to become a ring shaped structure and finally the two lips meet and close to a form a closed covering--the embryo plumule sheath. Five days after flowering when the embryo plumule sheath is about to form, an apical point of the plumule emerges on the inside. Then the primordium of the incomplete leaf emerges beside the apical point of the plumule. At the same time, the apical point of the radicle emerges at the base of the embryo while the top extends to form the cotyledon. The primary vascular bundles also differentiate from the inner tissues. On the 7th day after flowering, the various parts of the embryo--plumule, plumule sheath, radicle, radicle sheath, cotyledon and the embryo leaf will have all differentiated. From then on till maturity, the embryo body and its organs enlarge further and mature except for the plumule which continues to differentiate into the first and second leaves.

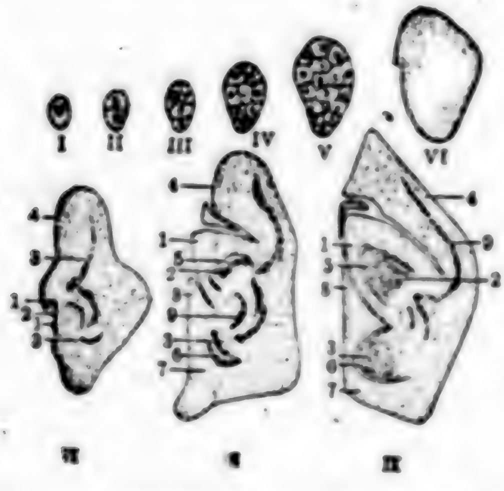


Diagram 54. Process of Development of the Embryo of Paddy Rice (Wuhan University Biology Department) I. Zygote II. Primordial embryo with two cells III. One day after flowering, the primordial embryo is pear shaped. V. Three days after flowering, the primordial embryo is pear-shaped. VI. Four days after flowering, the primordial embryo begins differentiation. VII. Five days after flowering, differentiation continues. VII. Seven days after flowering, the various parts of the embryo have basically completed differentiation. IX. Mature embryo.
1. Plumule sheath 2. Apical point of plumule 3. Apical point of radicle 4. Cotyledon 5. Young leaf 6. Root crown of radicle 7. Radical sheath 8. Outer embryo leaf 9. Preliminary vascular bundle.

The endosperm develops earlier than the embryo. Three to 3.5 hours after flowering when the endosperm nucleus has just taken shape, it beings its first mitosis forming two free endosperm nuclei. Then, the endosperm nuclei divide every hour and increase in number rapidly. One day after flowering,

the number of free endosperm nuclei may reach 50 to 80 distributed along the inner wall of the embryo sac at equal distances. Two to three days after flowering, the number of endosperm nuclei increases even more. They are connected by protoplasm and form a thin layer within the embryo sac (Diagrams 55, 56). Three to four days after flowering, a cell wall and an endosperm cell is formed among the free nuclei inside the embryo sac. Then, the layer of endosperm cells continues to divide and the number of layers of cells at the middle of the embryo sac increases. On the fourth day after flowering, the endosperm cells fill the embryo sac and begin to accumulate starch granules. At the same time the surface layer of the endosperm begins to differentiate into an aleurone layer. On the fifth day after flowering, the aleurone layer increases in thickness. From the 7th day after flowering until maturity, the number of endosperm cells remains unchanged (The number of endosperm cell, of a grain of geng rice is 180,000 or more; a grain of xian rice has 80,000 to 120,000 endosperm cells). The major activity is the continuing enlargement of the cells and the accumulation of nutrients. As the rice grain matures, the amount of dry substances increases and the moisture content lessens. At maturity, the majority of the cells in the endosperm have an accumulation of starch. Only the cells of the aleurone layer on the surface contain the major portion of proteinaceous granules and fats.

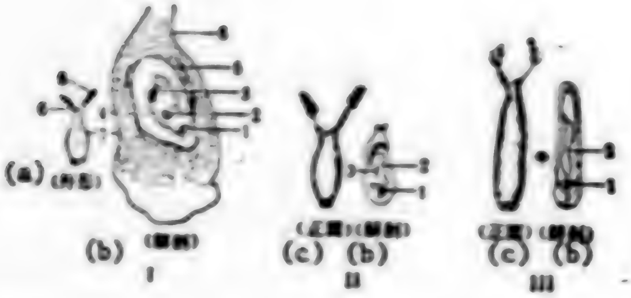
The pericarp and the seed coat that make up the seed's true coat have now been pressed together into a thin layer by the embryo and are not easily separated from each other and thus are generally referred to together as the seed coat.

B. Growth and Maturation of the Rice Grain

Following the development of the embryo and the endosperm, the ovary gradually expands and fills to form the rice grain (caryopsis). The rice grain along with the lemma and palea (called the husk) is called a grain. When processing the grain, the coarse husk (husk), the fine husk (pericarp), seed coat and aleurone layer) and the embryo are removed leaving the endosperm filled with starch called fine rice.

1. Growth of the rice grain

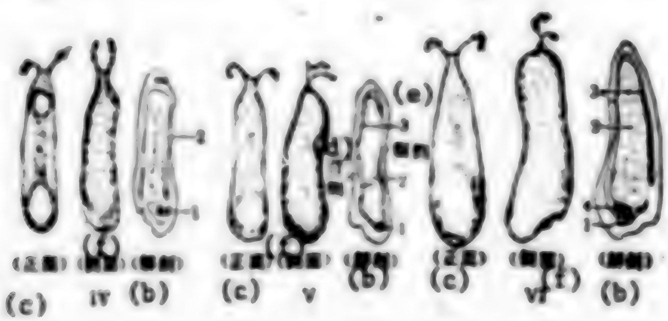
When paddy rice flowers, the ovary is located between the palea and lemma slightly slanted towards the palea. After fertilization the side of the ovary near the palea extends and widens and gradually reaches the tip of the glume. Then it stops its growth in length but begins to grow towards the two sides in width and gradually fills the space between the palea and lemma. Finally the ovary grows in thickness to reach the shape and the size of the rice grain (Diagram 57). Observations by the Wuhan University Biology Department of 7 varieties including early rice "Guangluai No 4" and late rice "Zaonong No 1" show early rice grows lengthwise 4 to 5 days after flowering and late rice grows the most lengthwise 7 to 8 days after flowering. Early rice grows the most in width about 6 to 7 days after flowering and late rice grows the most in width 9 to 10 days after flowering. Thickness of the rice grain is determined several days later.



I. The day of flowering
1. egg cell; 2. polar nuclear cell; 3. antipodal cell; 4. embryo sac; 5. ovule: 6. style; 7. ovary; 8. stigma

II. One day after flowering
1. primordial embryo from division of fertilized egg; 2. nucleus of endosperm; 3. antipodal cell.

III. Two days after flowering
1. pear-shaped primordial embryo; 2. endosperm nucleus.



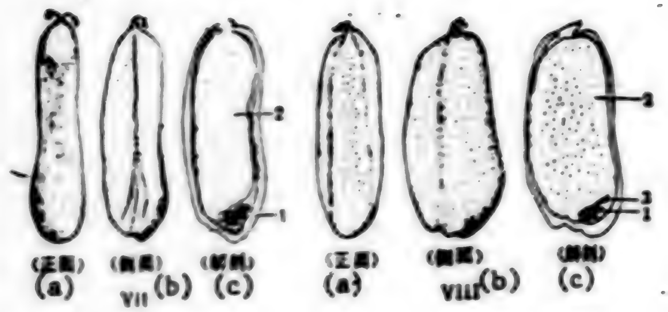
IV. Three days after flowering
1. primordial embryo; 2. endosperm cell layer

V. Four days after flowering
1. young embryo (with differentiated lip shaped protuberance) 2. endosperm cell; 3. aleurone layer

VI. Five days after flowering
1. plumule sheath; 2. endosperm; 3. aleurone layer; 4. cotyledon

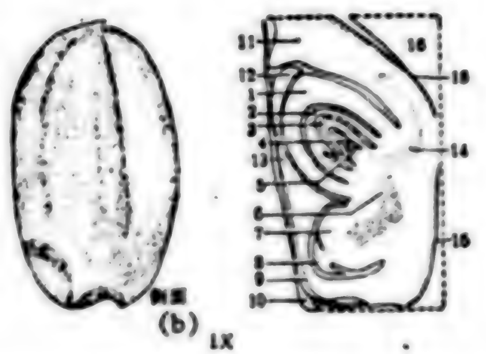
Diagram 55-(1)

Key: (a) outer shape
(b) dissection
(c) front
(d) backside
(e) mealy side
(f) side



VII. Six days after flowering
1. Embryo 2. Endosperm cell

VIII. Seven days after flowering
1. Plumule sheath 2. Endosperm cell 3. Cotyledon side



IX. Shape of the mature rice grain and dissection of the mature embryo
1. Plumule sheath 2. Incomplete leaf 3. First complete leaf 4. Second complete leaf 5. Apical meristem 6. Embryo axis 7. Radicle 8. Root crown 9. Radicle sheath 10. Pericarp and seed coat 11. Cotyledon (inner cotyledon) 12. Front scale 13. Outer cotyledon (degenerate) 14. Vascular bundle 15. Upper cortex (absorptive layer) 16. Endosperm tissue

Diagram 55-(2) Process of Development from Ovary to Caryopsis (Rice Grain) (Variety: "Wu nong zao") Huazhong Agricultural Academy) (1976)

Key: (a) front
(b) side
(c) dissection

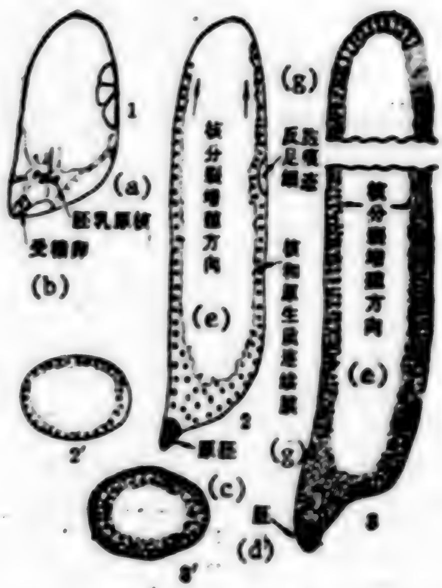


Diagram 56. Diagram of the Preliminary Period of Development of the Endosperm Tissues of Paddy Rice
(Hoshigawa Kiyoshin [2502 1557 3237 6024], 1975)

1. Embryo sac after fertilization shows primordial nucleus of endosperm dividing 2. Three days after fertilization. 2'. Horizontal cross section of 2. 3. Four days after fertilization. 3'. Horizontal cross section of 3.

Key: (a) Primordial nucleus of endosperm
(b) fertilized egg
(c) primordial embryo
(d) embryo
(e) Direction of nuclear division and multiplication
(f) tracks of antiposal cell
(g) Connecting membrane of nuclei and protoplasm

Key: (a) size of grain (mm)
(b) length
(c) width
(d) thickness
(e) maturity
(f) days after flowering

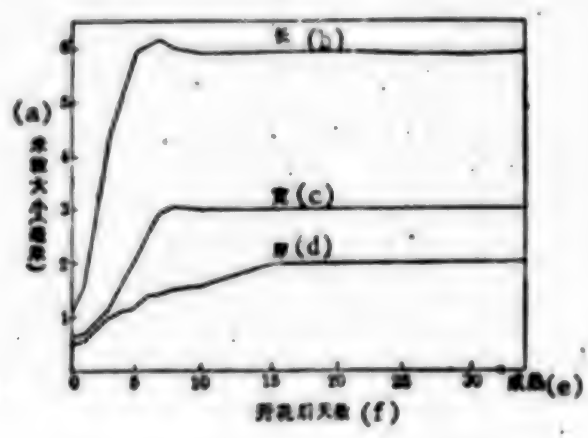


Figure 57. Growth of the Paddy Rice Grain (Variety: "Guangluai No 4")
(Central China (Huazhong) Agricultural College, 1975)

2. Maturation of the Rice Grain

By combining the changes in shape during the development of the rice grain and in the outer shape of the grain and in filling of the content of the grains, the process of maturation of the rice grain is generally divided into milky ripe stage, waxy ripe stage, complete ripening stage and withering ripe stage.

(1) Milky ripe stage: Milky ripe stage is the period popularly referred to as the filling period. The milky ripe stage begins when starch begins to accumulate in the rice grain and when a white translucent liquid appears. The milky ripe stage of early rice begins 3 days after flowering and that of late rice begins 5 days after flowering. Then the grain's content of white watery substance changes to a thicker white milky liquid or even completely disappears when the endosperm cells become hardened while the back of the rice grain still remains green. The husk changes to yellow and the shape of the rice grain is generally formed but the rice grain is not transparent. The milky ripe stage ends at this time and the waxy ripe stage begins. The milky ripe stage of early rice ends about 7 to 8 days after flowering and milky ripe stage of late rice ends 14 days after flowering.

(2) Waxy ripe stage: After the rice grain hardens the green color on the back of the rice grain gradually recedes until the color of the back surface's lengthwise grooves recede completely, marking the end of the waxy ripe stage and the beginning of complete ripening. The waxy ripe stage of early rice begins about 9 to 15 days after flowering and lasts for about 7 days. The waxy ripe stage of late rice begins about 16 to 18 days or 24 to 26 days after flowering and lasts for 9 to 11 days.

(3) Complete ripening and withering ripe stages: During the complete ripening stage the grain has turned yellow and hard enough to resist being broken. This is followed by the receding of color. When the sterile lemma and the branches dry up and wither, the branches at the tips may break. Marks of breakage across the rice grain may occur, indicating the beginning of the withering ripe stage. Generally paddy rice should be harvested in time during the complete ripening stage, otherwise there will be losses due to shattering.

The entire complete ripening stage of late rice lasts from 10 days to half a month longer than early rice.

However, it must be realized that the order of accumulation of nutrients in the rice grains on one panicle is the same as the order of flowering. Early flowering means nutrients are being accumulated early and maturity will be rapid and vise versa. Reports on measuring the greatest dry weight of the rice grain as an indicator show that the maximum dry weight of the first spikelet of a panicle can be reached 30 days after it flowers while the maximum dry weight of the last spikelet is reached 46 days after it flowers, a difference of 16 days. If the difference in the number of days the two flowers blossom

is counted, the actual maturity date will vary by 22 days. The rice grain at different parts of a panicle develops at different speeds and accumulates nutrients at different times. Often the nutrients cannot be distributed evenly to each rice grain and to each part of the panicle. These are all related to the yield of empty and semi-filled grains and immature white rice and rice with white at the middle.

III. Physiological Basis for Increasing the Number of Grains and the Weight of Grains

After the paddy rice plant flowers and is fertilized, the weight of the seed grain increases continuously. By physiological analysis it can be seen that this is due to the conversion of simple soluble substances (such as sugars) into complex and less soluble high molecular compounds (such as starch). The increases in the weight of the seed grain and accumulation of dry substances continue until the seed completely ripens (Diagram 58).

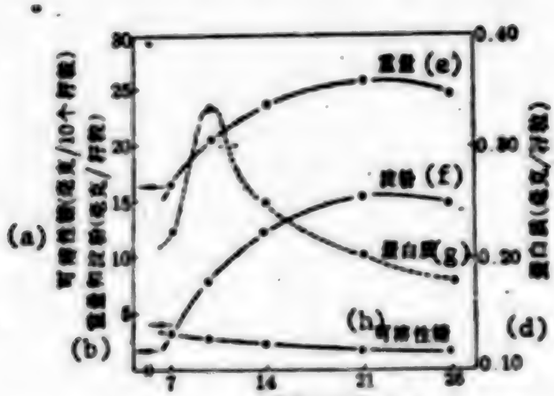


Diagram 58. Changes in Weight and Soluble Sugar, Starch and Protein in the Ripening Process of Paddy Rice "IR-8" ("Ke zi No 6") Seed Grain (Lyda. G. Baun, et al, 1970)

Key: (a) soluble sugar (milligrams/10 seed grains)
(b) weight and starch (milligram/seed grain)
(c) number of days after flowering
(d) protein (milligram/seed grain)
(e) weight
(f) Starch
(g) Protein
(h) Soluble sugar

We all know that to increase yield the two major objectives during the heading and ripening stages of paddy rice are to increase the number of grains (increase the fruiting percentage) and increase the weight (increase the 1000 grain weight). To achieve these two objectives, a physiological analysis must include these three factors: One is the amount of supply of photosynthetic products including the amount stored before heading and the amount of photosynthesized after heading. The second is the capacity of the product organs

to hold such products including the number of spikelets and the size of the grain hull. The third is the interconnection of the photosynthetic organs (leaves and green parts) and the products organs (rice grain), including the transportation of photosynthetic products, speed of transportation and amount transported.

A. Supply and Transformation of Photosynthetic Products

1. Source of photosynthetic products in the grain

The amount of photosynthetic products transportable to the seed grain is the main objective in increasing the number of grains and the weight of the grains. It includes the nutrients temporarily stored in the body of the rice plant (mainly the stem and leaves) before heading and the assimilated products after heading. Yin Hongzhang (3009 1347 4545) et al (1965) of the former Plant Physiology Institute of the Chinese Academy of Sciences proved in their study of 11 paddy rice varieties that the dry weight of each panicle increases by 2 grams from the time of flowering to maturity (Table 46). Of these 2 grans, 0.5 grams of dry substances come from the stem, constituting 1/4 of the weight of the panicle. Substances transported from the aged and weak leaves amount to between 0.2 and 0.3 grams, equivalent to 1/8 of the increased weight of the panicle. Thus, 2/3 of the weight of the seed grain consist of dry substances from the photosynthetic products of the green leaves after flowering (including green stems, glumes and awns). If all the leaves were removed after flowering, the weight of the panicle visibly drops. The amount of substances consumed by the entire plant after flowering was not included in the above calculations. Experiments show that between flowering and maturity, every 100 seed grains on the panicle consume about 1 gram of dry substance all of which are products of photosynthesis. Similar results obtained from C^{14} tracing experiments (Diagram 59) showed at maturity, 74 percent of the grain's carbohydrates came from photosynthesis after flowering. Thus it is not difficult to imagine that taking effective measures to raise the intensity of photosynthesis after flowering will greatly increase the fruiting percentage and the weight of grains.

Table 46. Comparison of the Average Dry Weight of the Panicle and Stem at Flowering and Maturity of Paddy Rice

Variety	Weight of panicle (gram)			Weight of stem (gram)	
	Weight at peak flowering	Weight at maturity	Weight of plant after removal of all leaves at flowering	Weight at flowering peak	Weight at maturity
853	0.551	2.756	1.578	2.286	1.697
261	0.669	2.712	1.637	2.243	1.621

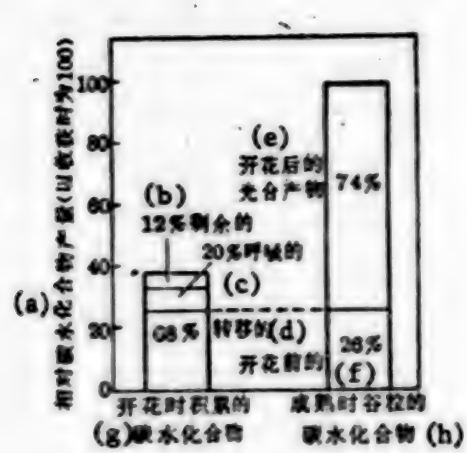


Diagram 59. Sources of Carbohydrates of Paddy Rice Grain at Maturity

Key: (a) Relative amount of production of carbohydrates (based on 100 at time of harvest)
- (b) 12% remaining
- (c) 20% from respiration
- (d) 68% converted
- (e) photosynthetic products after flowering 74%
- (f) before flowering 26%
- (g) Carbohydrates accumulated at time of flowering
- (h) Carbohydrates at time of ripening

Again according to Yin Hongzhang [3009 1347 4545] (1965), the amount of soluble sugar, starch, protein and cellulose in the stem gradually reduces from flowering to maturity (Table 47). At the time of maturity, the amount of soluble sugar and starch have almost all disappeared. This indicates that soluble sugar and starch are stored in the stem only temporarily and can be easily used. Half of the amount of protein in the stem at maturity is being transported elsewhere. The same reduction of these stored substances occur in plants whose leaves are all removed. This reduction in stored substances is also an indication that the stems gradually die out. It is important to notice that under normal conditions the cellulose in the upper and lower parts of the stem reduces by 10 percent at maturity but under conditions in which all the leaves of the plant have been removed, the reduction of cellulose at the bottom of the plant reaches 40 percent. This indicates that under normal conditions the cellulose that gives stiffness to the stems is not used or transported very much but when there is an insufficiency of nutrients (such as when the supply of photosynthetic products reduces because of the plant remaining green, insect pests, diseases, dampness and rain and overly dense growth), a large amount of cellulose will be utilized as nutrients, possibly causing lodging.

Table 47. Changes in the content of Organi: Substances in the Stem During the Period between Flowering and Maturity (Milligram/Plant)

(a) 物质种类		(b) 上部茎(穗下第2节间)			(g) 下部茎(穗下第4~5节间)		
		开花时 (c)	(d) 成熟时		开花时 (c)	成熟时 (d)	
			对照 (e)	去全叶 (f)		对照 (e)	去全叶 (f)
Total dry weight	总干重	448	362	339	610	330	302
Protein	蛋白质	23	9	10	17	10	9
Soluble sugar	可溶性糖	47	1	2	44	2	1
Starch	淀粉	22	3	3	90	3	3
Semi-cellulose	半纤维素	83	75	73	79	76	66
Cellulose	纤维素	188	116	121	143	132	87
Other substances	其他物质	142	168	171	128	107	137

Remark: Variety: Shenglixian, leaves removed at flowering time.

Key: (a) substan s
(b) upper stem (2nd internodes below the panicle)
(c) flowering time
(d) maturation time
(e) contrast
(f) leaves completely removed
(g) lower stem (4th to 5th internodes below the panicle)

2. Conversion of photosynthetic products

How do photosynthetic products (including those stored before heading) enter the seed grain? The major photosynthetic products is glucose. It must first be converted to sucrose before it can be transported from the leaves via the vascular bundles in the stalks to the vascular bundles on the back of the rice grain (on the side of the inner husk). After the sucrose enters the endosperm cell, it is synthesized into directly chained starch via the following steps.

$$\text{sucrose} + \text{UDP} \xrightarrow{\text{UDPG-F invertase}} \text{UDPG} - \text{fructose (represented by F)}$$

(uridine diphcphate) (Uridine diphosphate glucose)

$$\text{UDPG} + \text{PPi} \longrightarrow \alpha - G - 1 - P$$

(inorganic phosphorus) α-glucose-1-phosphorus)

$$\alpha\text{-G-1-P} + \text{ATP (or UTP)} \xrightarrow{\text{ADPG (or UDPG) phosphorylase}}$$

(adenosine triphosphate) (urine triphosphate)

ADPG (or UDPG) + PPi

ADPG (or UDPG) + G_n

(α-1,4-glucoside)

$$\xrightarrow{\underline{\text{diastase (ADPG starch} \quad \alpha\text{-1,4-invertase)}}} G_{n+1} + \text{ADP (or UDP)}$$

(direct chain starch) (adenosine diphosphate)

(urine diphosphate)

The process is different in higher plants. In such graminaceous plants as paddy rice, besides the major pathway of ADPG synthesis of starch, there is also the phosphorylation pathway but its function is less important:

$$\alpha - G - 1 - P + G_n \xrightarrow{\text{phosphatase}} G_{n+1} + P_i$$

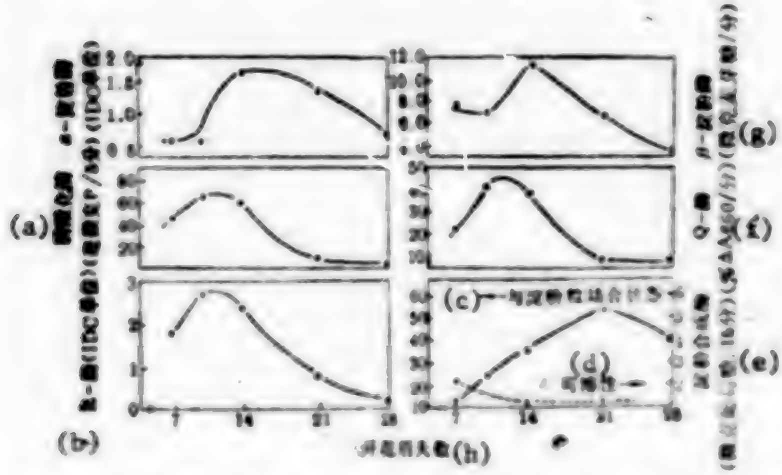


Diagram 60. Changes in the Activity of Synthetic Enzyme α and β-amylase, Phosphorylase, Q-enzyme, R-enzyme and ADP-glucose Starch During the Development of the Seed Grain of Paddy Rice (Lyda. C Baun et al, 1970)

Key: (a) phosphorylase α-amylase
(b) R-enzyme (1 DC unit)(millimicogram P/5 mole) (1 DC unit)
(c) combined state with granules of starch
(d) solubility
(e) diastase (microgram glucose/15 moles)
(f) Q-enzyme (% A660/mole)
(g) β-amylase (microgram maltore/mole)
(h) days after flowering

Studies indicate during the milky ripe stage phosphorylase and diastase are very active. But diastase is more effective in synthesizing starch from sucrose because its catalytic reaction is almost irreversible while the reaction of the phosphorylase is reversible. It can be seen from Diagram 60 that the height of activity of phosphorylase appears earlier (10 days after flowering) while the peak of activity of diastase appears later (21 days after flowering). Thus some people believe they function at different periods. Phosphorylase may be the forerunner of the diastase pathway.

As to the synthesis of branch chain starch, it is believed at present that branch chain starch is synthesized by the Q-enzyme (α-1,4-glucoside-6-glucomutase or called branching enzyme). These enzymes cut off starch

molecules at an interval of every 20 remnant glucose bases and connect them with the 6th carbon atom of the remnant glucose base of the direct chain to form a branch starch. Branch starch constitutes over 99 percent of the starch content in the Nuo [glutinous] rice and over 70 percent of the starch content in the xian rice. The possible pathway by which branch starch is synthesized can be illustrated in the following:

| A —O + Q enzyme ⟶ | B — Q enzyme + | C —— O

Provider body

| B —— Q enzyme + | D —— O ⟶ | B ↓ ——— O + Q enzyme

Receptor

Note: |—— direct chain starch's non-reducing base;

——O direct chain starch's reducing base;

——↓ α - 1.6 chain.

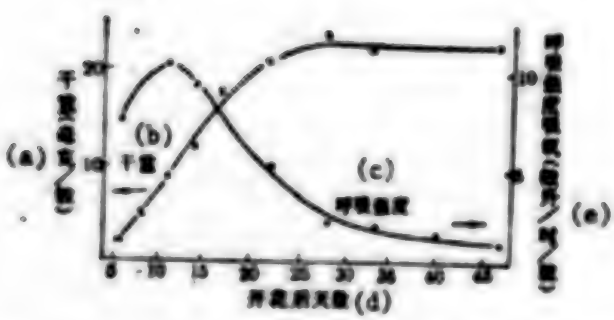


Diagram 61. Relationships Between Changes in Dry Weight of Paddy Rice Grains (Dehusked) and Changes in Intensity of Respiration

Key:
(a) dry weight (milligram/grain)
(b) dry weight
(c) strength of respiration
(d) number of days after flowering
(e) strength of respiration of oxygen intake (microliter/hour/grain)

It can be seen from the above that in the process of maturity of the paddy rice seed extremely complex and intensely material conversion takes place, these material conversions all take place under the catalysis of enzymes. All these activities including the biological synthesis of materials require sufficient amount of energy. Xia Shufang (115 0647 5364) determined that the respiration in the maturing seed is intense and the pace rises rapidly and peaks during the milky ripe stage when starch and dry substances are rapidly accumulating and increasing (Diagram 61). The basal material of respiration also come from the decomposition of starch in the seed grain. It can be seen from Diagram 60 that the activities of the series of hydrolytic starch enzymes--α-amylase, β-amylase, R-amylase all reach a peak. These amylase not only provide the basal material for energy sources but also provide the preliminary materials (lead substances) for synthesis of starch. It can be seen from this that synthesis and decomposition of substances at all times are both contradictory and in unity. In general, respiration is most intense during the milky ripe stage and then gradually weakens and levels off at a very low intensity. At this time, the seed will have completed its development and entered a dormant stage.

B. Capacity of the Productive Organs

The size and the weight of the grain are related not only to the amount of supply of photosynthetic products but also the capacity of the organs for photosynthetic products, i.e., the size of the husk. The size of the husk often functionally limits the development of the rice grain. Under conditions where filling is good and the husk is large, more filling substances enter the grain and the weight of the grain is heavy. If the husk is small, the filling material will cause the husk to burst open and cause split grains. Regardless of the conditions, the weight of the split grain will not be as high as that of normal grains.

The period that determines the size of the husk is around the period of meiosis i.e., at the end of reduction and division. This is because the capacity of the grain husk has already been basically established by this time. Thus the possibility of the weight of the grain reaching a certain level is determined. People often call this period as the first period determining the weight of the grain. During this time, good nutritional conditions and sufficient supplies of fertilizers and water are important to increase the size of the grain husk.

C. Direction and Speed of Transportation of Photosynthetic Products

Increasing the ability of assimilation by the leaves creates possibilities for the grain to be filled fully but to actually saturate the grain, stored substances (including the stored substances in the stem and leaf sheath) must be effectively transported to the grain.

Photosynthetic products depend upon two factors for their transportation and distribution to the grains.

1. The "push" of the "source" in the exporting organs

The "push" of the exporting organs refers to the ability to supply photosyn hetic products. When there are plenty of assimilted products and when the assimilated products surpass the amount needed by the assimilating organs themselves, the possibility that these surplus products are exported exists. The more assimilated products there are the greater the potential for export. But the absolute amount of assimilated product is only one side of the question. The final ability to supply such products depends upon the need of the organs themselves, the nutritional situation and the relative differential between the "exported" and the "imported" substances. It has been determined that the flap leaf has the greatest ability to asimilate substances, thus its ability to supply such substances is also great and it exports the most. The amount of assimilated substances exported by the reverse second and third leaves is proportional to their ability of assimilation (According to reports, during the milky ripe stage, the flag leaf, the reverse second, third and fourth leaves possess a percentage of assimilation of 52 percent, 22 percent, 7.7 percent and 17.5 percent respectively). But, when the amount of assimilated substances in the panicles is greater than that in the reverse second and third leaves, theoretically the amount exported should be small, but the second and third leaves still supply large amounts of substances to the panicles, thus using the amount of assimilated substances to simply explain this function becomes unsatisfactory. Here, the rapid growth of the panicle and the massive accumulation of nutrients for more assimilated products come into play. The nutritive condition also exerts a great effect here. In the photosynthetic products of the leaves of the paddy rice plant, the amount of soluble sugar is dominant while in the panicle there is more insoluble starch which is immobile. The soluble sugar which has lower "concentration" thus provides the driving force for transportation of materials to the panicle. It has been determined that the concentration of synthesized sugar under photosynthesis between 2 and 6 p.m. in the afternoon is 8.37 percent in the leaves > the 5.49 percent in the leaf sheath > the 5.4 percent in the stem and > the 4.31 percent in the grain.

2. The "pull" of the "storage" in the importing organs

The "pull" of the importing organs refers to the ability to compete for nutrients. The assimilated products from the leaves are transported to many parts and only those organs with a strong competitive ability will be able to get more. In general, the parts with a stronger growth and more prosperous metabolism are also often the organs with more growth substances that stimulate growth such as growth hormones. These constitute the "importing centers." The fact that the panicle becomes the "importing center" for the distribution of nutrients during the latter growth period of paddy rice is because it is regulated by its own metabolic intensity. Shen Yungang [3088 0336 6921] (1962) showed by experiment that if the leaves are removed,

the export of products of photosynthesis by the leaves ceases. (Table 48). Thus, the relationship between the "storage" and "source" is not a simple function of serving as a container but has its active influences. The reason why the fruiting percentage is low and the 1,000 grain weight is small when the paddy rice plant remains green and the leaves grow overly long is because the weakening of the "importing center," i.e., the panicle, has caused a stronger metabolism (nitrogen metabolism) in the leaves.

Table 48. Effect of Removing Panicles Upon the Export of Photosynthetic Products of the Paddy Rice Leaves (% Total Radiation Intensity)

(a) / (b) / (c)	I		II	
	(c)	(d)	(c)	(d)
(e)	13.4	81.0	20.1	57.4
(f)	0.5	3.7	3.7	6.3
(g)	84.8	—	71.4	—
(h)	2.2	8.7	4.6	20.4
(i)	0.0	0.3	0.2	3.7
(j)	0.1	1.8	0.0	4.3

Key: (a) number of the experiment
(b) treatment
(c) organ
(d) comparison
(e) Feeding $C^{14}O_2$ to leaf
(f) Leaf sheath (including that of the leaf fed with $C^{14}O_2$)
(g) panicle
(h) stem
(i) other leaves and sheath
(j) other tillers

In addition, the transportation of photosynthetic products is related to the distance between the "source" and the "storage." If the flag leaf is near the panicle, the photosynthetic products can be transported to the grain within 15 to 24 hours. The photosynthetic products of the reverse second leaf will take 24 to 72 hours to reach the grains and the photosynthetic products of the reverse third leaf will take over 48 hours. The shorter the distance the faster the transportation and the more the transported amount.

Another fact to be pointed out is that during filling the flag leaf makes the greatest contribution of dry substances to the panicle and the leaves at the bottom of the plant contribute less since the bottom leaves must also satisfy the needs of the root system (Table 49). If the leaves at the bottom of the plant wither and yellow too early, the supply of oxygen and materials to the roots by the leaves will be affected (the three internodes at the upper part generally do not have a differentiated aerate tissue and oxygen cannot be sent to the root via the internodes) as well as

the contribution of the upper leaves to the panicle. This is because the reduction in the function of the leaves has caused a reduction in the activity of the root system and in turn causes the functioning leaves during the latter period to weaken early. The root system not only provides the leaves with nitrogen, moisture and mineral elements but also provides some special amino acids and some plant hormones. Therefore, a reduction in the activity of the root system will necessarily cause a reduction in the intensity of photosynthesis and further reduce the percentage of fruiting and the weight of grains. This is also the reason for nourishing the roots and preserving the leaves during the latter growth period of paddy rice.

Table 49. Distribution of $C^{14}O_2$ Observed by the 8/0, 10/0 and 12/0 Leaves (Pulse Number/10 milligram) (Tanaka, 1961)

(a)		(b)	(c)		
			8/0	10/0	12/0
(d)	—	106	60	370	2883
(e)	12/0 (g)	140	106	180	95134
	11/0	210	66	130	0
	10/0	190	66	26860	0
	9/0	120	40	54	0
	8/0	70	61300	0	0
(f)	—	600	444	0	0

Key: (a) organ
(b) dry weight
(c) Distribution of $C^{14}O_2$ after absorption of $C^{14}O_2$ by the following leaves
(d) panicle
(e) leaves
(f) root
(g) 12/0 (flag leaf)

IV. Reasons for Formation of Empty and Semi-filled Grains and Methods of Control

It has been mentioned previously that during the flowering and fruiting stages of paddy rice, the yield of paddy rice is determined by the product of the number of panicles, the number of spikelets per panicle, the percentage of fruiting and the 1,000 grain weight. Of the four factors, it is generally easier to increase the number of panicles and the number of spikelets in a unit area. Therefore, increasing the percentage of fruiting and the weight of grains which is the same as reducing the percentage

of empty and semi-filled grains and raising the 1,000 grain weight are the major objectives during the latter period to increase the yield of paddy rice. But in paddy rice production, the empty and semi-filled percentage usually reaches 15 percent to 20 percent and even 30 percent to 40 percent, seriously affecting paddy rice yields. Thus, to analyze the causes of empty and semi-filled grains and the ways to prevent formation of empty and semi-filled grains is an important question in paddy rice production. Analysis by experiments shows that if the number of panicles and the 1,000 grain weight are similar, a difference of the empty and semi-filled percentage between 30 percent and 40 percent will cause a difference in yield of between 30 percent and 40 percent. A difference of 2 grams in the 1,000 grain weight will mean a difference in yield of 100 jin.

Empty grains and semi-filled grains are two different things. An empty grain refers to a grain that is not fertilized. A semi-filled grain refers to a grain that has ceased to develop after fertilization. The causes that produce empty and semi-filled grains, besides insect pest damage and diseases, can be divided into physiological causes and external environmental effects. The latter can directly bring about the former causes. They are analyzed separately below.

A. Physiological (Internal) Causes of the Occurrence of Empty and Semi-filled Grains

Generally speaking, the possibility of the weak spikelets on a panicle that differentiate and flower late to form empty and semi-filled grains is the greatest (Diagram 62). To observe the strong and the weak spikelets, we can perform the following experiment: At heading time remove all the leaves of the paddy rice plant or use a dark cover to cover the plant. At maturity we will discover that the paddy rice plant whose leaves have been removed or which have been covered will prouuce panicles with visibly reduced weight and the number of empty and semi-filled grains will increase in multiples. Experiments conducted by the Jiangxi, Jingan County Agricultural Bureau showed that removing all three leaves (flag leaf, reverse first and reverse second leaves) of a plant will cause the fruiting percentage to drop by 65.5 percent, the degree of maturity will only reach 74.3 percent, the 1,000 grain weight will drop nearly 2 grams and yield will be less by 36 percent (Table 50). The Jiangsu Academy of Agricultural Sciences experimented with the intermediate geng rice by removing the leaves and shielding the plant from light and obtained similar results (Table 51). If we observe each branch's filled grains, semi-filled grains and empty grains carefully, we will discover that the first grain of each branch is always fuller and the fullness of the grain reduces in the following order: 1 > 6 > 5 > 4 > 3 > 2 or 1 > 3 > 2. Of these, grains 2 and 3 are less filled and even become empty grains. Observation of the distribution of empty and semi-filled grains on a panicle shows that few branches are on the top and more branches are on the bottom. (Diagram 62).

Key:
(a) Milligram

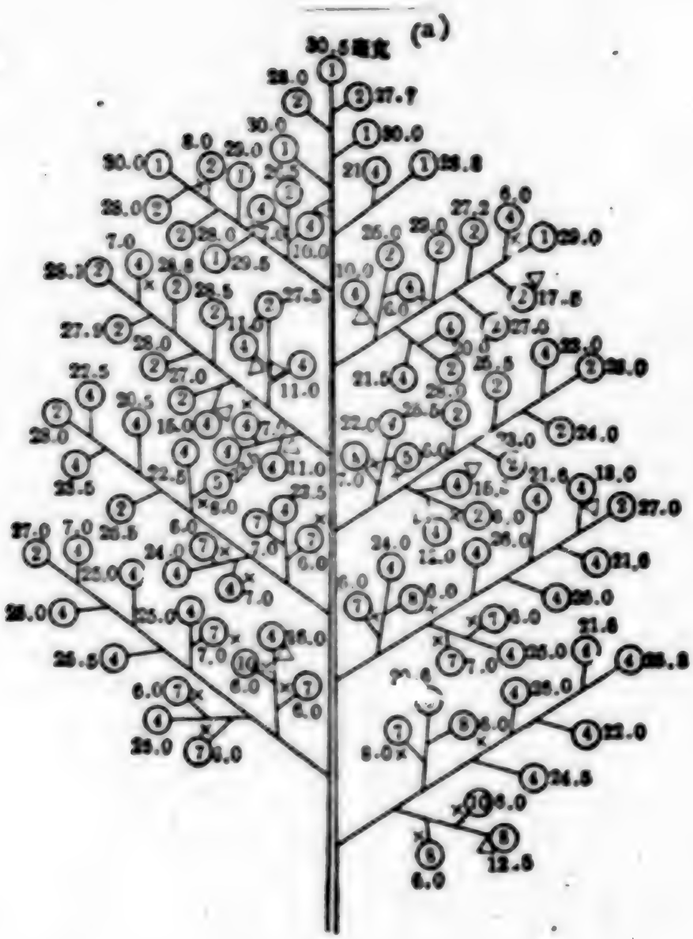


Diagram 62. Relationship Among the Position of Grains on Panicles, Order of Flowering and Empty Grains, Semi-filled Grains and Grain Weight. (Variety: late geng "E wan No 3," Hua Zhong Agricultural Academy, 1975) Explanation: 1. Flowering began September 12, ended September 21, Flowering stopped on the 3rd, 6th and 9th days due to low temperatures. 2. "X" indicates empty grains. "Δ" indicates semi-filled grains. 3. Numbers in circles indicate the day from the beginning of flowering, numbers outside of the circles indicate the weight of grain (milligram)

The percentage of empty and semi-filled grains caused by weak spikelets (generally about 5 percent of the total) in actuality reflects the effect of the amount of photosynthetic products of the rice plant upon the percentage of semi-filled and empty grains. The internal effects upon the percentage of empty and semi-filled grains are:

Table 50. Effect of Removal of the Upper Leaves Upon Yield and Percentage of Empty and Semi-filled Grains

	Complete removal of flag leaf	Complete removal of flag leaf and leaf below	Complete removal of 3 leaves	Comparison (none of the leaves removed)
Fruiting Percent(%)	93.5	74.2	65.5	94.4
Maturity degree(%)	91.0	74.2	74.3	98.5
1000 grain weight (grain)	25.7	24.9	24.6	26.5
Loss in yield (%)	3.9	21.1	36.0	0

Note: Tested variety was early xian "Miaojie," leaves removed when all panicles had headed

Table 51. Effect of Shielding from Light During Heading Period Upon Empty and Semi-filled Percentage

Treatment	Covered from light				
	Comparison	Flag leaf covered	Reverse second leaf covered	Reverse third leaf covered	All three leaves covered
Empty and semi-filled grain percent(%)	26.9	51.4	48.4	35.9	67.5
Percentage of increase (%)	0	+24.5	+21.5	+ 9	+40.6

* Degree of maturity (%): Soak grains in salt water of 1.06 density. Grains that sink are mature grains or full grains. Grains that float are immature grains, which we call empty and semi-filled grains. The degree of maturity is the number of grains that sank as a percentage of the total number of grains. This method is more standard and accurate than observation by eye.

1. Order and irreversibility of grain filling

Occurrence of empty and semi-filled grains and the development of the transportation system of the rice panicle (vascular bundles) are closely related. During the process of differentiation of the young panicle, the vascular

bundles in the panicle stalk separate one by one and separately extend into the spikelets and the branches. Filling takes place and substances are transported to the grains via this system of vascular bundles. Grains with large and plenty of vascular bundles generally do not easily become empty or semi-filled grains because the flow of nutrients is smooth. On a rice panicle, the spikelets that differentiate early (strong spikelets) usually fill up early and fast because the vascular bundles have developed early and are large and plentiful. Spikelets that differentiate late (weak spikelets) fill up late and slowly because the vascular bundles have developed late and are thin and few. In addition, the synthesis of sugars into starch also require energy from respiration. Xia Shufang (1115 0647 5364) (1964) proved by experiment that because strong spikelets can receive more sugar and their respiration is intense (Diagram 63), more photosynthetic products are "pulled" towards the grains. Weak spikelets show a weak respiratory intensity and the "pull" is weak. The photosynthetic products on a rice plant are always limited and under unfavorable conditions the order of emergence of full, semi-empty and empty grains on a branch of a rice panicle is generally 1 > 6 > 5 > 4 > 3 > 2 and 1 > 3 > 2. This is the reason empty and semi-filled grains on the upper branch are few and the lower branch have more empty and semi-filled grains. Experiments also prove that by removing the spikelets on the third branch and leaving the first and second branch will yield a percentage of empty and semi-filled grains of 4.2 percent. Conversely, if the third branch's spikelets are left and the first and second branch's spikelets are removed, the percentage of empty and semi-filled grains rises to 12.8 percent. On one branch, the same is manifested by removal of the first and the sixth grains (sic).

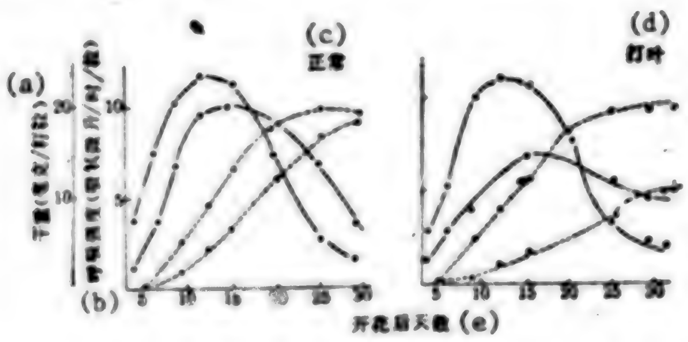


Diagram 63. Changes in Intensity of Respiration and Dry Weight of Grains at Different Positions

Note: • 1 position (strong flower)

o 2 position (weak flower)

—— intensity of respiration

--- dry weight

Key: (a) dry weight (milligram/grain)
(b) intensity of respiration (oxygen intake milliliter/hour/grain)
(c) Normal
(d) Defoliated
(e) Number of days after flowering

Filling of the grain not only has an order but also is irreversible. Within a certain period after flowering, those that have been filling will continue to be filled. Those that have not begun to fill during this period will not begin to fill later even if sufficient assimilated products are supplied. Here, the discontinuation of the development of the rice grain in the early stage and the amount of carbohydrates in the stem and the leaf sheath and the amount produced by photosynthesis at the time that is being transported to the rice grain are closely related, especially the former. This is also the reason why "healthy stem means large panicles."

The order of filling of the grain and the irreversibility are biological characteristics advantageous to the preservation of the seed of paddy rice. The characteristics enable the paddy rice during the beginning of the filling period to assure that when the products of photosynthesis are insufficient, ad hoc distribution of assimilated products will not occur (even distribution) and since part of the grains (weak spikelet) will not fill, the need for photosynthetic products by a part of the grains (strong spikelets) will be satisfied. But, this ability of adjustment occurs only during the beginning period of filling. As soon as the strong spikelets begin to fill the distribution of photosynthetic products to the grains will quickly become even and the amounts of nutrients received by the strong and the weak differ only in degree rather than in the existence or non-existence of the supply. If the leaves' photosynthesis is strong, the source of nutrients is rich, most of the seed grains will be able to mature normally. Although filling of the grain on the weak parts of the plant will be hindered at the beginning, filling of these grains catch up later on and at time of harvest, 95 percent of the seed grains will be full.

After recognizing this objective pattern of filling of the seed grains, we can by human efforts increase the accumulation of substances stored in the stem and prevent the synthesis of photosynthetic products and nitrogen to form useless proteins by drying the field and removing the yellow leaves before panicle differentiation and heading. The fields in which there is a tendency of early withering can be applied with "gap" fertilizers (pellet fertilizers) to increase the sugar content of the plants by providing the plants with sufficient nitrogen and reducing the conflict between supply and demand for nutrients during the beginning period of filling, reducing the formation of empty and semi-filled grains, increasing the weight of the grains and percentage of fruiting and thus increasing yield.

2. Varieties and plant type

Studies indicate the plant type of the short stem varieties with the three upper leaves that are short and erect (the angle between the leaves and the panicle axis is small) have a higher rate of utilization of light energy and their percentage of empty and semi-filled grains is low. This is because plants of the varieties with erect leaves can receive the stronger

light in the colony (Table 52) while varieties with bent leaves or curly leaves receive less exposure to light in the colony because the leaves shade each other. Therefore, there is a reduction of the photosynthetic products produced after heading and the increase in dry substances in the grain is less than that in the grain of plants with erect leaves in the colony thus, a reduced yield is produced. Experiments conducted by the Wuhan University (1973) also indicate that with a leaf surface coefficient of between 6 and 7 when cultivating late rice, the use of varieties with the three leaves that are short and erect constitutes an important factor in reducing the percentage of empty and semi-filled grains. "Guangluai No 4," "Erjiuqing" and "Kezi No 6" (known as IR-8 abroad) are some of the varieties at present that utilize light energy better and yield a low percentage of empty and semi-filled grains (Table 53). Thus another an important way of reducing the percentage of empty and semi-filled grains is by cultivation and breeding. In addition, keep in mind the shape of the panicles. Since the production of photosynthesis of a single plant is always limited, an overly large-shaped panicle (over abundance of spikelets per panicle) will waste nutrients and cause an increase in the percentage of empty and semi-filled grains. This is also a problem to heed in cultivation and breeding work.

Table 52. Relationship Between Intensity of Light Received by the Leaf and Angle of the Leaf (Wuhan University, 1973)

Angle between flag leaf and panicle axis	Intensity of light on the bottom part of the second leaf (meter-candles)
10 ~ 15	8000 ~ 8500
70 ~ 75	5000 ~ 5500
80 ~ 90	4000 ~ 4500

Table 53. Relationship Between Yield and the Angle of the Flag Leaf of Early Rice Varieties (Wuhan University, 1973)

Maturity characteristics	Variety	Entire growth period (days)	Length of panicle neck (cm)	Angle between flag and panicle axis	Yield (jin)
Early maturing	Er jiu qing	104	2.96	10.9	996.2
	Er jiu nan No 3	105	3.16	11.5	943.7
	Hu xian No 1	104	1.45	12.7	850.0
Intermediate maturing	Qing dong No 6	108	3.26	12.4	975.0
	Qing xiao jin zao	106	1.26	10.0	936.2
Late maturing	Guang lu ai No 4	119	2.86	12.3	1143.8
	Ba si zao ba	118	1.64	18.5	1031.2
	Ke zi No 6 (IR-8)	118	2.49	11.9	1027.5

B. External Conditions That Cause Formation of Empty and Semi-Filled Grains and Methods of Control

The external conditions that cause formation of empty and semi-filled grains are temperature, moisture, fertilizers and light. Observations of the triple-cropped paddy rice in the middle and lower reaches of our nation's Chang Jiang regions indicate the greatest cause is temperature.

1. Temperature

The most suitable temperature for flowering, fertilization and filling of paddy rice is between 25°C and 30°C. If the daytime average temperature is lower than 20°C (the highest daily temperature is lower than 23°C) or higher than 35°C, large numbers of empty and semi-filled grains will emerge.

(1) High Temperatures: High temperatures affect the percentage of empty and semi-filled grains during two periods. One is the flowering period and the other is the filling (milky ripe) period.

The artificial climate laboratory of the Shanghai Plant Physiology Institute (1976) showed by experiment that a high temperature of 30°C during the flowering period caused visible damage and under a temperature of 38°C the formation of full grains was impossible (Table 54). The range of changes indicated in Table 54 shows the development of grains of early rice during the flowering period is towards the two extremes of becoming full grains and empty grains and the proportion of becoming the intermediate type (semi-filled grains) is small.

Table 54. Fruiting of Early Rice Under Different Temperatures During Flowering Period (Shanghai Plant Physiology Institute, 1976)

Temperature °C	Percentage of filled grains %	Percentage of semi-filled grains %	Percentage of empty grains %
28	80.9	1.0	18.1
30	52.2	2.3	45.5
32	32.6	2.3	65.1
35	18.9	4.3	76.8
38	0	11.5	88.5

Note: Treatment lasted for 5 days, duration of light was 12 hours a day, intensity of light was 25,000 meter-candles.
Full grains: Seed grains that sink in water
Semi-filled grains: Seed grains that sink after soaking for 24 hours. Remaining are empty grains.

Table 55. Percentage of the Capability of Filling of Spikelets After Hidh Temperature Treatment at Different Growth Stages (Shanghai Plant Physiology Institute, 1976)

Temperature (°C)	Spikelet development stages*			
	-1	0	1	2
30	38.5	41.7	95.6	100
32	38.9	40.9	94.5	100
35	23.4	49.1	92.7	100
38	0	8.6	100	100

* -1: Those which have not yet flowered
0: Flowering has occurred but the ovary has not extended.
1. The ovary has extended but smaller than 1/3 the length of the glume.
2. The ovary has extended and its length is between 1/3 and 2/3 the length of the glume.

Then, what stage of flowering is more affected by high temperatures? Table 55 shows that at the beginning of high temperature treatment, the probability of filling of spikelets which have not yet flowered or which have completed flowering but the ovaries have not extended (the "-1" and "0" spikelets) is not large, less than 50 percent. Especially the spikelets that have not flowered have a lesser probability of filling after treatment under high temperatures. With a temperature of 38°C, the probability is zero and with the rest, the probability does not surpass 40 percent. But as soon as the ovary visibly extends ("1" and "2" spikelets), the great majority of the spikelets will be able to continue to fill and fruit even after such high temperature treatment. With the various temperatures, the probability of filling is above 90 percent. It can thus be seen that the most damage to paddy rice caused by high temperatures during the flowering period is done to spikelets that have not flowered and spikelets that have completed flowering but their ovaries have not extended. This is to say, high temperatures destroy the fertilization process and cause the formation of empty grains. As soon as the ovary extends (completion of fertilization), the resistance to heat of the spikelet greatly increases. In the large field, high temperatures exert the greatest effect during the peak flowering period, thus high temperature damage during this period must be prevented.

Experiments also show that high temperatures above 35°C will cause a reduction of the percentage of germination of the pollen on the stigmata. With a (comparative) temperature of 28°C the percentage of germination of the pollen is 58.8 percent while with a temperature of 35°C the percentage is only 15.2 percent. The results of artificial hybridization and high temperature treatment (Table 56) show the percentage of empty grains caused by damage to pistils with a temperature of 35°C is higher, indicating that a temperature of 35°C causes more damage to the female reproductive organs.

Table 56. Effect of High Temperatures Upon Percentage of Empty Grains During Flowering Period of Paddy Rice (Shanghai Plant Physiology Institute, 1976)

Treatment	Percentage of empty grains, %
Comparison, (28°C)	9.8
Hybridization of the female whose pistil has developed with a temperature of 28°C and a male whose pollen has developed with a temperature of 35°C	32.5
Hybridization of the female whose pistil has developed with a temperature of 35°C and a male whose pollen has developed with a temperature of 28°C	58.7

Note: Experimental variety was Erjiuqing.

In addition, the Shanghai Plant Physiology Institute's Artificial Climate Laboratory used X-rays to make continuous photographs of the empty grains and discovered that after subjecting the plant to a temperature of 38°C during the flowering period, the grain visibly "receded," i.e., the filling substances that entered the grain at the beginning later flowed out of the seed and disappeared.

According to experiments, during the filling period, a (rather high) temperature of 32°C lasting for 5 days caused the plant to yield a fruiting percentage similar to that when the plant was subjected to a temperature of 28°C but the 1000 grain weight dropped 0.5 grams. Continuous treatment for 15 days resulted in a 3 percent reduction of the fruiting percentage and a drop in the 1,000 grain weight of less than 1 gram. The main reason was due to early withering of the root system caused by high temperatures, a reduced functioning level of the leaves, a reduced content of chlorophyll and a shortened period for absorption of photosynthetic products, causing the maturity period to shorten, the filling to become insufficient, a drop in the 1,000 grain weight and a slight reduction in yield. But under a (overly high) temperature of 35°C, the situation was different. Not only did the 1,000 grain weight drop but the percentage of empty and semi-filled grains also rose greatly. Experiments indicate that temperature of 35°C lasting 5 days will cause the percentage of fruiting to drop by 10 percent to 15 percent, increase the semi-filled percentage and the number of semi-filled grains and cause the 1,000 grain weight to drop by 0.42 grams to 1.85 grams. A temperature of 35°C lasting 10 days will increase the damage and even greater damage will result when that temperature persists for 15 days (Table 57). It can be seen from Table 57 that with a high temperature of 35°C, the percentage of empty and semi-filled grains reduces more as a result of exposure during the early part of the milky ripe period while the

1,000 grain weight reduces more as a result of exposure during the latter part of the milky ripe period. The effect upon production (as measured by the product of the decreases in the fruiting percentage and the 1,000 grain weight) is manifested by the greatest damage during the latter part of the milky ripe stage (at the time with normal conditions the paddy rice plant is in a period when the rate of filling is the highest) and the damage visibly reduces after the waxy ripe period.

High temperatures not only affect the function of the leaves and ability of the grains to receive substances but also affect the accumulation of starch inside the paddy rice seed. The period from filling to waxy ripe of early rice is the high temperature season when "there is slight heat (July 7), the southerly wind blows for 18 days and the heat scorches the bamboo trees in the front yard." When the southwesterly wind blows the highest temperature persisting for days may be above 35°C and the temperature difference between day and night time is small. During the night, the plant's respiration is extremely intense thus causing a reduction in the accumulation of substances and a rise in the percentage of empty and semi-filled grains and a drop in the 1,000 grain weight. To change this situation, the broad masses of poor and lower-middle peasants implemented the method of irrigating during the day and draining during the night to lower the temperature and raise the humidity and widen the temperature difference between day and night so that more substances can be accumulated in the grains. Observations made by the Shanghai Municipal Weather Bureau (1974) and Yutang Brigade of the Maqiao Commune in Shanghai county, Shanghai Municipality, showed that if the temperature difference between day and night is increased by 1°C, the 1,000 grain weight will increase by 0.5 gram to 1 gram (Table 58). With temperatures above 35°C, fields with relatively mushy soil or fields with prosperous growth can be irrigated at 11 o'clock in the morning and drained between 2 and 3 o'clock in the afternoon. Rapid irrigation and rapid drainage will adjust the temperature and humidity of the field during the high temperature period at noon (Table 59).

Table 57. Effect of Overly High Temperatures Upon Empty and Semi-filled Grains and 1000 Grain Weight of Paddy Rice
(Shanghai Plant Physiology Institute, 1976)

Treatment No.	I	II	III	I+III	I+II	II+III	I+II+III
Reduction in 1000 grain weight (gram)	0.64	1.85	0.42	1.23	1.99	1.66	3.24
Reduction in percentage of filled grain (%)	14.2	12.7	10.5	31.6	65.1	25.3	72.6

Remarks: [continued on next page]

Remarks: [for table 57 on preceding page]

Tested variety Erjiuqing.

I. Indicates treatment with 35°C for 5 days during early period of milky ripe period

II. Indicates treatment with 35°C for 5 days during latter period of milky ripe period.

III. Indicates treatment with 35°C for 5 days during waxy ripe period

I + II. Indicates treatment with 35°C for a total of 10 days during early and late periods of milky ripe period

I + III. Indicates treatment with 35°C for a total of 10 days during latter part of milky ripe period and waxy ripe period

I+II+III. Indicates treatment with 35°C for a total of 15 days during early and late parts of milky ripe and waxy ripe periods

Table 58. Relationship Between 1000 Grain Weight and Temperature Difference Between Day and Night 10 to 25 Days After Flowering of Early Rice

Temperature difference between day & night °C	6.6~7.0	6.1~7.5	7.6~7.8	7.9~8.0
1000 grain weight (gram)	25.0	25.9	26.1	26.4

Table 59. Comparison of Temperature and Humidity in the Early Rice Field When Irrigated and When Not Irrigated

Elements / Type	Temperature & humidity at panicle		Temperature & humidity at 10 centimeters above ground		Ground temperature at depth of 5 centimeters
	temperature	relative humidity	temperature	relative humidity	
irrigated field	31.2°C	83%	31.4°C	87%	29.5°C
nonirrigated field	32.7°C	71%	33.1°C	70%	30.5°C

They also experimented with spraying water over the field. Each mu was sprayed 400 to 500 jin of water before noon when the glumes were closed, reducing the temperature by 1°C to 2°C immediately and increasing the re ative humidity by 10 percent to 15 percent but the effect was not lasting (1 to 2 hours).

In addition, the Shanghai Plant Physiology Institute, the Shanghai Municipal Weather Bureau and the Shanghai County, Yutang Brigade (1975) experimented with Vitamin C, growth hormones, gibberillin ("920") and kinase. At the beginning period of the milky ripe period of early rice (6 to 10 days after heading) the plant was subjected to a high temperature of 35°C for 5 days. Chemicals were sprayed twice on the first and the third days. Preliminary results indicated vitamin C, growth hormone, gibberellin and kinase all had a definite effect upon preventing damage by high temperatures which was mainly manifested in the increase in the percentage of full grains and the 1,000 grain weight (Table 60). Since all substances that preserve vegetation such as nucleotide and urea may be effective when sprayed, this needs further experimentation.

Table 60. Effects of Some Substances in Preventing High Temperature Damage to Early Rice

(1)	(2)	(3)		(4)		(5)		(6)	
		50ppm	500 ppm	20ppm	200 ppm	20ppm	200 ppm	20ppm	200 ppm
(7)	15.5	16.8	16.6	16.2	16.6	16.0	16.3	16.3	16.0
(8)	29.9	40.8	44.6	35.4	43.0	37.9	41.1	37.7	29.8

Note: Experimented Variety Erjiunan No. 2.

Key:
(1) Item
(2) Comparison
(3) Vitamin C
(4) Gibberellin
(5) Kinase
(6) Growth hormone
(7) Total 1000 grain weight (gram)
(8) Percentage of full grains %

(2) Low temperatures: The effect of low temperatures upon the percentage of empty and semi-filled grains of paddy rice, upon early rice in particular, results from the damage caused during the middle period of panicle differentiation (panicle bearing period) while the damage to late season rice is mainly due to damage during the flowering period and the filling period.

(a) Panicle bearing period of early rice: Low temperature damage to early rice during the panicle bearing period is manifested mainly in an increase in the number of empty grains. The Shanghai Plant Physiology Institute marked plants at three different stages of growth under average temperatures of below 20°C lasting continuously for 4 days: Plants whose spikelets on

the first and second branches at the bottom were still undergoing meiosis; plants whose spikelets on the first to the fourth branches at the center and bottom were still undergoing meiosis; and plants whose spikelets on the first to third branches at the top were undergoing meiosis. The results showed that the degree of damage by low temperatures was closely related to the state of development of the rice panicle. The plants whose branches at the bottom were undergoing meiosis were harmed the most with 44.7 percent empty grains. The plants whose branches at the center and the bottom were undergoing meiosis were harmed less severely with 35.3 percent empty grains and the plants whose branches at the upper part were undergoing meiosis were harmed the least with 26.3 percent of empty grains (Table 61).

Table 61. Relationship Between the State of Development of the Pollen Grain and Low Temperatures (Shanghai Plant Physiology Institute, 1976)

	Position on branch	Percentage of empty grains(%)	Percentage of unfilled pollen grain (%)	Remark
Plants with bottom branch in meiosis	top part middle part bottom part	48.3 46.8 37.8	- 42.4 29.4	Top branches have flowered. Middle branches 2 to 3 days after meiosis.
Plants with middle and bottom branches in meiosis	top part middle part bottom part	46.9 31.3 22.2	45.5 30.3 14.3	Top branches 2 to 3 days after meiosis
Plants with top branches in meiosis	top part middle part bottom p t	28.0 26.5 23.4	23.9 15.7 --	Panicles have not completely headed. Branches at the middle and lower parts have not yet begun meiosis

Note: Variety experimented was Erjiunan No 2 observed during filling stage and maturation stage

We can see from the state of development of the pollen grain and the percentage of empty grains at the various branch positions that low temperatures damage early rice mainly during the period 2 to , days after meiosis when the pollen's quadruplet and microspore are developing (In foreign literature this is known as the monospore pollen period's two time contraction period. Experiments conducted by the Biology Department of Wuhan University show this contraction phenomenon is not natural but induced by the fixatives used by man). Branches and panicles that are undergoing meiosis and those that have not reached meiosis are only slightly harmed or not harmed at all. Present varieties and techniques of fertilization

cannot reduce damage by low temperatures. Thus, low temperatures mainly damage the development of pollen grains because there is a positive correlation between unfilled pollen grains and empty grains.

Studies conducted by the Agricultural Irrigation Work Station in Hengdong County in Hunan Province in 1973 showed low temperatures between 14.3°C and 14.6°C during this period (meiosis stage) caused formation of 854 empty anthers among 2673 anthers, 171 to produce thick pollen walls, 1042 degenerate anthers and a 77.1 percent empty and semi-filled grains. This further proved that low temperatures during the panicle bearing period mainly affect the development of the pollen grain.

The reason why low temperatures harm the development of pollen grains is not yet understood and opinions differ. It may be because low temperatures cause the villiform cells (that provide nutrients for development of the pollen grains) on the inner wall of the anther to enlarge and fatten or to wither overly early and dissolve, thus cutting off the channel by which nutrients are transported to the pollen grain. This would cause the development of the pollen grain to cease or slow the development of the pollen grain so that the pollen grain does not fill up fully and loses its ability to develop.

At present there is no especially effective way to prevent low temperature damage to early rice (late season rice sometimes also encounters such situations). Since the young panicle of early rice at this time is already 60 centimeters above ground, deep water irrigation of 10 centimeters will not directly protect the young panicles, but can correspondingly raise the temperature at the panicles. Thus, in some areas the method of draining during the day and irrigating during the night and irrigating deeply to increase temperature is used to reduce low temperature damage. Observations made by the Shanghai Municipal Chuanshan County Weather Station indicate that if river water is used to irrigate the field about midnight (it is best to irrigate from one end and drain from the other end of the field and continue irrigation for 4 hours) the water temperature in the rice field can be raised by 3°C and the ground temperature at a depth of 5 centimeters can be raised by 2°C. Daytime drainage should be done at 8 o'clock in the morning so that the temperature can be increased by shallow irrigation.

(b) Flowering and filling periods of late season rice: In the Shanhai area, the surface temperature gradually turns cold in September. By then the cold air of the north has begun to move towards the south and 3 to 5 days of dropping temperatures easily occur. If late season rice heads and flowers during this period, "raised panicle heads" will often occur (i.e., "not sinking head"--grains that cannot fill and fruit normally). This is caused by a rise in the percentage of empty and semi-empty grains (50 percent and above) and also is an important cause of the reduction of yield of late season rice in the Shanghai area.

The Shanghai Plant Physiology Institute's Artificial Climate Laboratory (1975) showed that during the flowering period, low temperature damage is mainly done during the peak flowering period and the lower the temperatures and the longer the duration the more damage is done. (Diagram 64).

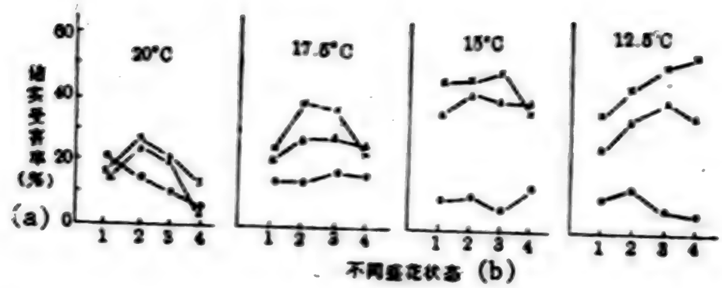


Diagram 64. Effect of Different Low Temperature Upon Fruiting of Panicles at Different Flowering States

Note: o___o Treatment for 3 days; Δ——Δ Treatment for 4 days; x——x Treatment for 5 days

1. One day after flowering peak; 2. flowering peak; 3. one day prior to flowering peak; 4. two days prior to the flowering peak.

Key: (a) Percentage of damage to fruiting (%)
(b) Different peak flowering states

It has been mentioned before that paddy rice given temperatures below 20°C will protect its spikelets by closing its flowers. But after 3 days, even though the flowers are still closed, the fruiting percentage will drop drastically. X-ray photographs tracing the fruiting activities of spikelets that open at different times under low temperatures (Table 62) showed that when a plant placed in a temperature of 12.5°C for 5 days was moved to conditions where the temperatures were between 25°C and 20°C, the plant was able to continue to flower and the peak of flowering was reached at 10:45 a.m. All florets flowering before the flowering peak were able to fruit at least partially while all florets that flowered after the flowering peak were unable to form full grains. Thus, it can be seen that closing of the flowers cannot resist damage from a long period of low temperatures.

Their preliminary experiments also indicate damage by low temperatures during flowering is mainly done to the reproductive organs; the male reproductive organs are damaged more severely (Table 63).

The effect of low temperatures during the filling period seems to be reversible, that is, with a temperature of 20°C or below, filling temporarily stops and when the temperature returns to normal filling begins again.

Table 62. Fruiting After Flowering Following a Low Temperature (12.5°C) as Traced by X-ray Photos (Shanghai Plant Physiology Institute, 1975)

月日 (g)	开花时间 (a)	总开花数 (b)	实粒数 (c)	半秕粒数 (d)	秕粒数 (e)	空粒数 (f)
10.11	8:00~10:00	17	2	5	9	1
	10:00~10:45	17	7	5	2	2
	10:45~11:15	4	0	1	1	3
	11:15~12:00	2	0	1	0	1
	12:00~13:00	1	0	1	0	0
10.12	8:00~13:00	3	0	1	0	2
10.13	8:00~13:00	8	0	0	2	6
10.14	8:00~13:00	0	0	0	0	0
10.15	8:00~13:00	1	0	0	0	1
10.16	8:00~13:00	1	0	0	0	1

Explanation: After 5 days in a temperature of 12.5°C, the experimented variety "Jianong No 14" was moved to conditions with temperatures between 25°C and 20°C on October 11.

Key: (a) flowering time (d) Number of half semi-filled grains
(b) total number of florets (e) Number of semi-filled grains
(c) number of full grains (f) Number of empty grains
(g) Month/day

Table 63. Effect of Low Temperatures on the Percentage of Empty and Semi-filled Grains and Reproductive Organs During Flowering Period of Late Rice (Shanghai Plant Physiology Institute, 1975)

Treatment	Empty and semi-filled grain(%)
Hybridization of pistil developed in 25°C as female and stamina developed in 20°C	54.2
Hybridization of pistil developed in 20°C as female and stamina developed in 25°C	42.2
Hybridization of pistil developed in 25°C as female and stamina developed in 15°C	73.8
Hybridization of pistil developed in 15°C as female and stamina developed in 25°C	68.4

Analysis of the above experiments shows that to prevent low temperatures from causing late season rice to "raise the panicle heads," the main method is to prevent low temperature damage during the peak flowering period. This is to say, in large areas of late season rice, the plants must head fully before the safe full heading period. The many years of weather data and

statistics of low temperature damage to late season rice in the Shanghai area compiled by the Shanghai Municipal Weather Bureau show that if an average temperature of below 20°C persists continuously for 4 days (considering at the same time a lowest temperature of below 17°C lasting for 2 consecutive days) is tak-- as an indicator of the safe full heading period of late season rice, then the late season rice in Shanghai that heads fully by September 23 has a record of safe heading in eight out of ten years. Full heading after September 27 will increase the chances of encountering low temperatures and the later the more dangerous. (Table 64).

Table 64. Percentage of Assurance of Full Heading and Avoiding Damage by Low Temperatures of Different Full Heading Periods of Late Season Rice in the Shanghai Region

(a)齐穗期(月/日)	9/17	9/19	9/21	9/23	9/25	9/27	9/29	10/1
减数分裂期或开花期遇低温的累积年数 (b)	2	4	5	6	9	16	22	30
不受低温为害的保证率(%) (c)	96	92	90	88	82	68	56	40

Key: (a) Full heading time (month/day)
(b) Cumulative number of years in which low temperatures occurred during the reduction and division period or the flowering period
(c) Percentage of assurance of avoiding low temperature damage

(c) Measures to prevent low temperature damage to late season rice: To prevent low temperatures from damaging the late season rice, the broad poor and lower-middle peasants and scientific technicians joined together and implemented many effective measures. They are now introduced below:

Comprehensive agricultural measures: Comprehensive agricultural measures to make late season rice head fully before the safe full heading time is an important measure to prevent late season rice from "raising panicle heads." Three measures are included: One is to properly combine the varieties so that they will safely achieve full heading. The general principle is to establish the plan for the entire year but pay attention to the present. Start out by "seeking high yields in stable yields" (high yielding late geng often has a long growth period, is late ripening and is greatly endangered by the [cold] wind; for early maturing varieties, the danger from the wind is less, but the yield is comparatively less) and grasp the method of "planting late maturing geng as the first crop, intermediate maturing late geng as the main rice crop and the early maturing late geng as the closing crop." Sometimes late maturing or intermediate maturing late geng are used as the closing crop planted sparsely to extend the seedling age

so that the shortness of the growth period in the large field can be remedied. This will assure safe full heading and realize higher yields. The second is the cultivation of strong seedlings of an appropriate seedli ; age by shallow transplanting and shallow irrigation (Table 65) in order to realize early germination and early maturation. The third is to regulate fertilization and irrigation, paying special attention to the fact that thermal organic fertilizers should be the major type of fertilizers applied to late season rice and chemical fertilizers should be supplementary. The base manure should be the main type of fertilizaer and sidedressings should be supplementary. Base manure should be applied sufficiently and sidedressings should be applied early.

Table 65. Relationship Between Depth of Transplanting and Early Germination and Early Heading (Shanghai Municipal Weather Bureau, 1974)

Sowing date	Transplanting date	Depth of transplant, cm	Heading date
July 15	August 2	8.4	September 27
July 15	August 2	6.5	September 21

Experimented variety "Jianong No 14."

Regulate the microclimate in the field. In recent years, many regions have launched work in regulating the microclimate in the field under the revolutionary spirit that man will conquer nature. They conducted experiments in raising the temperatures in the rice field to reduce low temperature damage and achieved definite progress. There are two major methods: One method is to irrigate the field (with a deep water layer) the night before the arrival of low temperatures and drain the field in the day to increase the temperature of the field. Observations made by the Shanghai Municipal Weather Bureau and the Yutang Brigade of the Shanghai County showed that the highest temperature of the river water during the middle and last ten days of September occurs at 5 o'clock in the afternoon and the lowest temperature occurs at 7 o'clock in the morning. The highest temperature of the water of the river is between 25°C and 26°C and the lowest temperature is between 23°C and 24°C. The difference in temperature is slight. The occurrence of the highest and lowest temperatures in the rice field happens about 2 to 3 hours earlier than the highest and lowest temperatures of the river water. Temperature in rice fields which have been drained dry generally rise rapidly after 9 o'clock in the morning to above the atmospheric temperature and above the water soaked fields (in the daytime). At dusk and afterwards the temperature in the rice field rapidly drops to below the temperature of the river water. Thus, irrigation at night and draining during the day can increase the temperature of the rice field. If a water layer of 2 cun is irrigated at night (from 2000 to 2300 hours), the temperatures at the panicles can be raised by 1°C to 2°C during the night on a clear day. The

desired temperature is reached 3 to 4 hours after irrigation stops. During rainy days, the rain water in the field must be drained and river water introduced into the field (it has been determined that during the first ten days in September, the ground temperature at a depth of 10 centimeters is about 25°C whereas the temperature of the rain water is only 20°C). Their experiments also showed that when low temperatures occurred on September 26, 1973, and when the average temperature on the 26th was 19.2°C and the average temperature on the 27th was 18.3°C, irrigation and lack of irrigation caused a visible difference in the percentage of empty and semi-filled grains. The fields with an irrigated deep water layer of above 2 cun yielded 6 percent empty and semi-filled grains while the fields with an irrigated water level of 1.5 cun yielded 12.8 percent empty and semi-filled grains and the field which was not irrigated yielded 22 percent empty and semi-filled grains. This shows that using water to increase temperature can partially regulate the microclimate in the field, reduce or prevent the adverse effects of the macroclimate and stimulate high yields in late season rice. The second is the use of heat retaining agents to increase the temperature: The Shanghai Municipal Academy of Agricultural Sciences irrigated the field with a temperature retaining agent (sodium naphthenate 30 jin/mu of emulsion) every day from September 17 to 22, 1974. Six hours after irrigation with the agent, the average temperature of the rice field was higher by 1.0°C to 1.5°C than that in fields not irrigated with the agent and higher than that in the compared fields by over 2°C. Full heading occurred 1 day early and the 1000 grain weight increased by 0.9 grams. A combination of the two methods described above may yield even better results.

Use and cultivation of cold resistant varieties: Use and cultivation of cold resistant varieties are basic measures to solve the problem of low temperature damage to late season rice causing a high percentage of empty and semi-filled grains (inner cause). The resistance to low temperatures of the late season rice varieties being planted in the Shanghai area at present varies (Table 66).

Table 66. Resistance to Low Temperatures of Different Late Season Rice Varieties (Science and Technology Station of the Malu Commune of Jaiding County, Shanghai, Shanghai Normal University Biology Department, 1974)

(a) 抽穗日期 / (b) 空秕率% / 品 (c) 种	9月23日 (d)		9月26日 (g)		9月28日 (h)	
	主茎 (e)	分蘖 (f)	主茎 (e)	分蘖 (f)	主茎 (e)	分蘖 (f)
嘉农14 (i)	33.06		53.42	41.94	71.5	
嘉农485 (j)	18.24	12.99	48.72	22.79	51.94	29.79
马选4 (k)	32.19	18.81	49.18	26.51	69.72	35.49
沪选19 (l)	13.0	8.33	23.26	10.91	18.29	22.22
农虹73 (m)			28.91		53.04	48.81

Key: (a) heading date
(b) percentage of empty and semi-filled grains
(c) variety
(d) September 23
(e) main stem
(f) tiller
(g) September 26
(h) September 28
(i) Jianong 14
(j) Jianong 485
(k) Maxuan 4
(l) Huxuan 19
(m) Nonghong 73

The above experiments show that "Huxuan No 19" has a stronger tolerance to cold and "Jianong No 14" has a poorer tolerance to cold (of course the conditions at various places may not be equal).

Qi Zhi [7871 1807] (1976) conducted a survey and discovered that a variety called "Hegu" (also called "Tuangu") planted at 2,500 meters above sea level in the Yunnan Plateau (the world's highest elevations for planting rice are at Madengba in Jianchuan County and Xiyinpan in Ninglang County in Yunnan, and Yenyuan County in Sichuan) is extremely tolerant to cold. It can be sown and cultivated in the large fields in a daily average temperature of below 10°C and the temperature needed for it to head and flower is just 16°C and above. Only a temperature lower than 16°C and persisting for 2 to 3 days will cause formation of empty and semi-filled grains. The future of introducing this variety into the middle and lower reaches of the Chang Jiang area (the latitudes are the same) or using it as the parent for hybridization for the cultivation of new late rice varieties that can resist or avoid low temperature damage (some places call low temperatures "cold dew wind") is bright.

In addition, in Nanning and Lingshan areas in Guangxi, the method of spraying the outside of the roots with phosphorus before the arrival of cold fronts has achieved definite results in protecting the crops from the threat of low temperatures and in preventing "raised panicle heads." They used two methods to spraying the phosphorus: The first method was to add 20 jin of phosphorous fertilizer into 100 jin of human urine and the mixture was stirred until the contents bubbled. Then the contents were kept sealed for 7 to 15 days. At the time of use, each jin of the content was diluted with 20 jin of clean water. The second method was to apply 1 jin of phosphorous fertilizers per mu diluted by 100 jin of clean water and allowed to stand for 24 hours before use. The people of Lingshan used this method and waged a people's war mobilizing 150,000 to 160,000 people for a continuous battle. They carried out a total spraying of 600,000 mu [some mu were sprayed more than once] and effectively prevented low temperature damage to crops and "raised panicle heads." In contrast, experiments showed that each mu sprayed with phosphorus increased yields by 40 jin to 80 jin compared to fields not sprayed with phosphorus. The annual yield increased by 12.2 percent.

The results of using such plant hormones as "920" to stimulate early full heading and flowering to avoid the effects of low temperatures are not uniform and further studies are still needed. Some units sprayed 20 ppm of "920" before heading and brought about early heading by 2 to 3 days, thus avoiding the effects of low temperatures.

2. Moisture

Moisture affects the formation of empty and semi-filled grains of paddy rice in two ways: One is the moisture in the paddy rice field and the second is the humidity in the air. Of course, these two are related.

(1) Moisture in the field: The demand for moisture by the various growth stages of paddy rice is not the same. Formation of empty and semi-filled grains of paddy rice may occur in two stages of the growth process of paddy rice: One is the pollen mother cell meiosis stage and the other is the milky ripe stage. A deficiency of water during the period from the emergence of the quadruplet to the formation of the pollen grain will cause some or all of the spikelets on some of the branches to develop incompletely. Moreover, spikelet development will cease at a certain stage forming deformed spikelets and empty and shrunken pollen containing little or no starch. The ovary and the stigma will shrink causing an increase in the percentage of empty and semi-filled grains. The damage is similar to that caused by salt or floods. Deficiency of water during the period from heading to the milky ripe stage damages mainly the transportation of organic matter to the panicles. If the deficiency is serious, the export of assimilated products in the leaves will be hindered causing a lot of empty and semi-filled grains.

Thus, in the management of irrigation and the degree of mushiness of the field, a sufficient amount of water during these two periods must be assured. During the reduction and division stage, a diagnosis of the period of development (reduction and division stage) can be made by "pulling of the three eyes." During the milky ripe stage, the field must be shallowly and frequently irrigated so that the field is clear every morning and the supply of water must not stop too early before maturation.

(2) Humidity in the air: Dryness of the air due to dry winds refers to "dry winds that cause insufficient filling of the grains." Experiments conducted by the Yutang Brigade in Shanghai County of Shanghai City in 1973 showed that at the time of flowering and fertilization, the percentage of empty and semi-filled grains increases as the number of hours of strong winds (wind speed greater or equal to 8 meters second) and aridity (relative humidity smaller or equal to 75 percent) increase (Table 67). The reason for "dry winds causing insufficient filling of the grains" is that strong winds and aridity cause the pistil's stigma to reduce the amount of its sticky secretion, shortens the life of the pollen and causes mechanical damage.

Table 67. Effect of Wind and Dry Weather Upon the Percentage of Empty and Semi-filled Grains During the Flowering and Fertilization Period

Number of hours of strong winds (≥ 8 meters/second)	12	11 ~ 10	9 ~ 7	6 ~ 3	2 ~ 0
Average percentage of empty and semi-filled grains (%)	35.3	21.6	15.1	13.2	13.1
The number of hours of relative humidity $\leq$ 75 percent		10-7		6-1	
Average percentage of empty and semi-filled grains (%)		17.6		13.5	

Aridity and dryness not only affect flowering and pollination of the paddy rice but also cause the flag leaf to wither and yellow, an increase in the percentage of empty and semi-filled grains and a reduction in the 1,000 grain weight (Table 68, 69).

Table 68. Relationship Between Different Methods of Management of Water in the Field and Withering and Yellowing of the Leaves Under Dry Weather Conditions During the Middle Part of Filling of Early Rice

Date (month/day)	Water in field	Highest temperature (C°)	Smallest relative humidity	Amount of evaporation from surface of leaves (mm/day)	Difference of leaf temperature and air temperature (C°)	Percentage of wither- and yellowing of flag leaf (%)
7/21	thin water layer	33.2	76	4.1	+ 1.1	30
7/25	no water	32.1	73	2.7	+ 2.3	50
7/31	no water	31.5	66	0.9	+ 2.9	70

Table 69. Effect of Green Leaves on Panicles and Wilted Leaves on Panicles Upon the 1000 Grain Weight During the Waxy Ripe Stage of Early Rice (Main Stem)

Color of leaf	Date (month/day)	1000 grain weight (gram)	Date (month/day)	1000 grain weight (gram)	Change in 1000 grain weight (gram)
half yellow leaves on panicles	8/1	25.4	8/3	26.4	+ 1.0
all yellow leaves on panicles	8/1	25.7	8/3	24.2	- 1.5

Addressing the situation above, the Yutang Brigade of Shanghai County of Shanghai used the method of reducing temperatures and raising the humidity by irrigating the field in the morning with a layer of cool water 2.5 centimeters to 4.5 centimeters deep (in the summer the temperature of the water in the river is lowest at 7 o'clock in the morning) and taking measurements at noon. The temperature in the field dropped by 1°C and the

temperature at the soil surface dropped by 1.5°C to 2°C, the relative humidity increased by 4 percent and the microclimate in the field was improved. This was beneficial to reducing the percentage of empty and semi-filled grains.

3. Fertilizers

Fertilizers are the food for plants. An over abundance or deficiency of fertilizers will both cause the plant to remain green during the latter growth period, or to grow too prosperously or hellow and wither early, increasing the percentage of empty and semi-filled grains and lowering the weight of grains.

The growth stages during which fertilization and the nutritional condition in the rice field will cause an increase in the percentage of empty and semi-filled grains are the vegetative growth period, young panicle differentiation stage, the early period of jointing and the filling and maturation periods.

(1) Overly late and overly abundant application of nitrogen fertilizers during the vegetative growth stage will delay young panicle differentiation and the growth period of the panicles and in particular will cause the late season rice to remain green and mature late. This causes the flowering and fertilization or filling period of the plants to be affected by low temperatures and creates increases in the percentage of empty and semi-filled grains.

(2) Application of nitrogen fertilizers during the beginning period of young panicle differentiation when the nitrogen content in the body of the plant is already high will cause photosynthetic products to distribute themselves more in the leaves than in the stems and young panicles. This causes the flag leaf and the reverse second leaf to differentiate and grow overly large. During the latter period the leaves become overly long and drooping and the colony becomes too dense. Poor aeration and poor light permeability affect the photosynthesis of 4/5th of the leaf surface area thereby reducing the accumulation of photosynthetic products. This results in an increase in the percentage of empty and semi-filled grains.

(3) Overly abundant application of nitrogen during the latter period [sic] of young panicle differentiation (period of formation of the pollen grain) will cause a sharp rise in the nitrogen content of the leaves, stem and panicles during the middle period of young panicle differentiation and lead to an increase in the percentage of empty and semi-filled grains during the latter period (mainly as empty grains) (Table 71). The effect of this situation upon the empty grain is reflected in the over abundance of nitrogenous fertilizers causing the pollen to develop poorly and preventing the pollen from developing on the stigmata. Surveys show that during those periods application of 30 jin of nitrogen per mu will bring about 15 pollens developing but an application of 60 jin per mu will lower the number

Table 70. Effect of Different Growth Trends Upon the Structure of the Colony and the Percentage of Empty and Semi-filled Grains During the Panicle Bearing Period of Paddy Rice

Type	Leaf surface coefficient	Dry weight (gram/plant)		Length of main stem's 9th leaf (cm)	Length of main stem's 10th leaf (cm)	Length of main stem's 11th leaf (cm)	Empty and semi-filled grain percentage (%)
		Leaf	Leaf sheath				
Normal growth trend	6.15	0.212	0.255	25.9	26.5	21.5	17.9
Overly properous growth trend	6.86	0.195	0.174	25.7	28.3	26.8	28.9

Tested variety: "Ainanzao No 1."

of developments to below 10. If the amount of fertilizers is reduced to 20 jin per mu, the number of developments will increase to above 30. It is known from analysis of the nitrogen content of the anther than an application of 30 jin of nitrogen per mu causes the protein nitrogen to increase slowly during the pollen's binuclear stage and the protein nitrogen to increase rapidly during the trinuclear stage. The amount of soluble nitrogen (amino acid and nitrate nitrogen) increases sharply during the binuclear stage and surpasses the amount of protein nitrogen (insoluble nitrogen). When 60 jin of nitrogen fertilizers were applied per mu, the increase in protein nitrogen did not undergo a period of gradual increase but continued to increase until the trinuclear stage. Soluble nitrogen rapidly decreased in amount during the binuclear stage. This process is exactly the opposite of changes in the content of soluble nitrogen in other parts of the rice plant. The content of carbohydrates is lower when the plant is fertilized by a high concentration of nitrogen during the trinuclear stage than that of a low concentration of nitrogen. This is because carbohydrates are used in abundance for synthesis of proteins. As respiration intensifies, basal materials become insufficient and less starch is accumulated, causing a shortage of energy resources during pollen development and extension. Empty grains are thus produced (sterility).

(4) An overly heavy application of nitrogen fertilizers prior to jointing will cause the nitrogen in the soil to become too abundant, a deficiency of potassium, the second and third nodes at the bottom part of the paddy rice stem to overly extend, the mechanical tissue of the stem to develop

Table 71. Relationship Between Consumption of Nitrogen Fertilizers and Percentage of Empty and Semi-filled Grains (Ishizuka, Y 1971)

Total amount of nitrogen fertilizers applied (jin/mu)		0	10	20	40	80
Content of nitrogen	panicle	1.18	1.26	1.25	1.33	1.36
	leaf and stem	0.40	0.36	0.64	1.79	1.96
Percentage of empty and semi-filled grains %	Main stem	19	21	37	59	65
	1st tiller panicle	13	18	50	76	82
	2nd tiller panicle	7	22	31	84	93

poorly, thus weakening resistance to breakage, bending and lodging. Lodging that occurs before heading will cause poor pollination, poor light permeability, reduction in total photosynthesis, harm to the transport system, hindrance to transportation of nutrients and moisture, increase in the number of empty and semi-filled grains, reduction of the 1000 grain weight and a reduction in yield. Studies indicate lodging that occurs during heading will cause a 40 percent to 50 percent reduction in yield. Lodging that occurs during the milky ripe stage will cause a 30 percent reduction in yield and lodging that occurs during the waxy ripe stage will cause a 10 percent to 20 percent reduction in yield.

(5) Remaining green or early withering before heading: The paddy rice plant that develops normally should yellow to an appropriate extent before heading. As described by the poor and lower-middle peasants of the Yutang Brigade in Shanghai County: "When the wind blows the paddy rice leaves must make sound. The leaves must be pointed so as to prick the palm. Upon entering the field the plants do not tangle the feet and the leaves must be short for the paddy rice grain to be strong." If at this time the color of the leaves is too green, the flag leaf too large, and the leaves droop in the morning when covered by dew, then the plant is remaining green. If before heading the leaves yellow too much and heading is not uniform and is weak, then these are signs of early withering. The changes in the color of the leaves of the paddy rice plant in actuality reflect the content of carbon and nitrogen. An overly yellow color indicates a correspondingly abundant accumulation of carbohydrates and an insufficiency of nitrogen. After heading the photosynthetic ability rapidly drops causing a drop in the 1000 grain weight and an increase in the percentage of empty and semi-filled grains. An overly green color indicates an abundance of synthesized nitrogen in the stems and leaves. This causes a slower speed in the transportation of carbohydrates from the stems and leaves to the panicles. A lesser amount is

also transported. Similarly, it also causes an increase in the number of empty and semi-filled grains and a drop in the 1000 grain weight.

In general, the amount of fertilizers being applied (especially nitrogenous fertilizers) and the percentage of empty and semi-filled grains are closely related. The Agricultural Science Institute of Changsha Municipality of Hunan Province and the Hunan Teachers College (1975) experimented with the method of application of fertilizers involving "two stimulations and one control" (application of 2/3 of the total amount of sidedressing of fertilizers at the early growth period and application of the remaining 1/3 during the latter period of growth. Fertilizers were not applied i.e., controlled during the middle growth period. The early growth period refers to the beginning period of tillering, the middle growth period refers to the young panicle differentiation period and the latter period of growth refers to the time of emergence of the flag leaf, i.e., the gap period. The total amount of sidedressing is 20 jin of urea per mu, the same in the following). This method of fertilization produces a much smaller percentage of empty and semi-filled grains than the method of "one heavy application at the beginning" (all of the side-dressing is applied during the early growth period) and the ordinary method of fertilization (application of 1/2 of the total amount of sidedressings during the early growth and middle growth periods without applying any sidedressing during the latter growth period) (Table 72).

Table 72. Effect of Different Methods of Application of Nitrogen Upon the Percentage of Empty and Semi-filled Grains of Paddy Rice

Treatment	Total number of grains per panicle	Number of filled grains per panicle	Number of empty grains per panicle	Percentage of empty and semi-filled grains (%)	Yield per mu (jin)
I One heavy application at the beginning	65.15	50.0	15.15	23.20	655
II Ordinary method of application	64.84	48.3	16.55	25.36	640
III "Two stimulations and one control" method of fertilization	64.07	52.7	11.37	17.76	685

Experimented variety was "Xiang-6"

They believe, after physiological analysis, that the method of "two stimulations and one control" changes the plant type, increases the content of chlorophyll in the leaves and the light intensity upon the leaves (Table 73, 74) so that the fruiting percentage is effectively raised.

Table 73. Effect of Different Methods of Application of Nitrogen Fertilizers Upon the Length of the Last Three Leaves

Treatment*	Length of leaf (centimeters)		
	Boot leaf	Reverse second leaf	Reverse third leaf
I	30.0	36.0	32.0
II	31.0	40.5	31.5
III	26.0	32.0	31.0

* I, II, III represent the same treatments as in Table 72, the experimented variety was Xiang-6. Determination was made after heading.

Table 74. Effect of Different Methods of Application of Nitrogen Upon the Content of Chlorophyll in the Leaves and Amount of Light Intensity Upon the Leaves

Treatment	Content of chlorophyll (dry weight %)	Light intensity* among plants (percentage of natural light intensity)		
		Upper Part	Middle Part	Lower Part
I	0.266	60.06	18.00	7.81
II	0.288	64.02	7.54	9.60
III	0.347	70.00	22.00	11.66

* (1) Upper part means at 10 centimeters measuring from tip of plant downward
Middle part means at the middle of the plant
Lower part means at 10 centimeters above ground from surface of soil

(2) The number of treatment refers to the same treatment listed in Table 72, the measured variety is Xiang-6 measurements taken during the milky ripe period.

According to the above analysis, a better method of fertilization in ordinary fields is to apply a larger amount of sidedressing during the early growth period (the beginning period of tillering) and a supplementary sidedressing

for the panicles during the latter period of growth which is also called fertilizers-to-preserve-the-spikelet (If there is a growth trend in which the plant remains green, such fertilizers need not be applied or only applie. to plants that are yellowing). Avoid application of nitrogen fertilizers during the young panicle differentiation period. Of course such application must be coupled with good management of irrigation and control of mushiness in the field. If the field is dried properly before the beginning period of young panicle differentiation, an over absorption of nitrogen during the middle growth period can be controlled. Fields in which the plants tend to remain green can be dried lightly before heading. According to the experiences of the Beigang Brigade of the Qincun Commune in Fengxian County in Shanghai Municipality, fields in which the plants have lodged during the latter period of growth can be sufficiently irrigated to reduce loss of yield.

4. Light

Since 95 percent of the dry substances in the rice grain comes from photosynthesis (the percentage is higher after heading), the intensity of light undoubtedly affects the formation of empty and semi-filled grains of paddy rice greatly.

Within certain limits, the intensity of photosynthesis increases with the increase in the intensity of light. It is generally believed that under the most suitable conditions, photosynthesis reaches "light intensity saturation" when the leaves of paddy rice are in a sunlight intensity of 0.6 calorie/centimeter^2/minute (i.e., when the intensity of sunlight surpasses of sunlight during sunny days in our nation's north and south generally can satisfy the paddy rice plant's need for light. But during damp and rainy days, the intensity of photosynthesis will drop.

Studies done by Xiao Yihua (5135 5042 5478) (1962) of Wuhan University show that when the light is blocked, the percentage of empty and semi-filled grains visibly rises (natural light of 63,000 meter-candles was shaded to allow only 1/4 to 1/5 or 11,666 meter-candles to shine on the subject in the experiment) (Table 75).

Table 75 shows the paddy rice plant is most sensitive to weak light during the quadruplet stage in the development of the pollen grain and less sensitive during the heading and flowering stages. Early rice is more sensitive to weak light than late rice.

The reason why the paddy rice plant is most sensitive to weak light during the quadruplet period of pollen development is because weak light causes the nonprotein nitrogen in the panicles to accumulate and become poisonous. This causes a reduction in the amount of carbohydrates available for the development of the pollen grain. Their studies indicate in weak light (or overly dense planting conditions), spraying 1 percent of potassium chloride or 0.01 percent boric acid will stimulate transportation of substances to the panicles and reduce the effect of weak light that causes formation of empty and semi-filled grains.

Of course, indirect effects of light affecting the percentage of empty and semi-filled grains are also manifested in how varieties, planting density and fertilization and irrigation controls are affected. These have been discussed previously and will not be repeated here.

Table 75. Effect of Shade at Different Periods Upon the Percentage of Empty and Semi-filled Grains of Paddy Rice

品种 (a)	处理 (b)	空秕率 (c) (%)	千粒重 (d) (克)	产量 (e) (%)
南特号 (早稻) (f)	对照 (g)	8.0	28.0	100
	I	12.7	28.1	100.9
	II	34.4	27.3	70.8
	III	30.1	27.9	81.8
特白八号 (中稻) (f)	对照 (g)	13	27.9	100
	I	15.5	27.2	95
	II	30.9	26.3	66.5
	III	28.0	27.9	93.6
老来青 (晚稻) (f)	对照 (g)	8.1	29.7	100
	I	10.2	28.9	94.7
	II	25.9	27.8	70.8
	III	20.5	29.4	89.1

Note: I; 12 to 1½ days under weak light during formation of pistil and stamina of main stem
II: 12 to 14 days under weak light during quadruplet period
III: 12 to 14 days under weak light during heading and flowering period

Key:
(a) Varieties
(b) Treatment
(c) Empty and semi-filled grains (%)
(d) 1000 grain weight (gram)
(e) Yield (%)
(f) Nante (early rice)
(g) Control
(h) Tebei No 8 (intermediate rice)
(i) Laoliaqing (late rice)

C. Problems Concerning Percentages of Empty and Semi-Filled Grains in the Propagation of Plants and Seed Propagation of Hybrid Paddy Rice

Hybrid seed propagation and cultivation and propagation of male sterile lines of hybrid paddy rice are two important components in the utilization of heterosis of paddy rice. But, in propagation, the flowering periods or the flowering times of the male sterile line and the restorer line or of

the male sterile line and the sterile-free line often do not coincide. This problem together with the enfolding of the neck of the male sterile line [often] prevent completion of pollination and fertilization causing a high percentage of empty grains, 70 percent to 80 percent or even higher and seriously affecting yield. Thus, planting 100 mu of hybrid rice requires 3 to 5 mu of hybrid seed propagation beds and 0.1 mu to 0.15 mu of sterile line propagation beds. Raising the fruiting percentage in hybrid seed propagation and cultivation of the sterile line is still an extremely important question in the development of hybrid rice.

1. Missing of the flowering periods and their adjustments

In the present hybrid combinations of hybrid paddy rice, the growth period of male sterile line varieties is shorter than that of the restorer line varieties. Coupled with the complexities of weather conditions (temperature and light) and conditions of fertilization and irrigation, the flowering periods of the various lines often do not coincide and the fruiting percentage is thus reduced. According to present experiences, the following measures can be taken to adjust the flowering periods so that they will coincide:

(1) Accurately time the sowing periods of the male and female by properly grasping the difference in the leaf ages at sowing time of the male and the female based upon the growth periods of the male (restorer line or sterile-free line) and the female (sterile line) in that locality.

(2) Sow the males at different periods to extend the flowering period. Surveys conducted by the Hyiangxi Provincial Academy of Agricultural Sciences indicate that in hybrid seed propagation during autumn, the male sterile line has a long flowering period and the duration between the beginning of heading and full heading is 12 to 13 days and the duration between the beginning of flowering and completion of flowering is about 15 to 18 days. The flowering period of the restorer line is short. The duration between the beginning of heading and full heading is about 5 to 6 days and the duration between the beginning of flowering and completion of flowering is about 7 to 10 days. Thus, the males need to be sown in two separate groups 8 to 9 days apart so that the beginning period of flowering of the male sterile line (female) and the latter flowering period will meet with the pollen of the male.

(3) Timely forecast and actively adjust the flowering period. Regardless of how correctly the difference in the sowing times of the male and the female is determined, the flowering periods may still fail to coincide because of the differences in seedling age, quality of the seedling and conditions of fertilization and field management. To assure that the flowering periods will meet, the growth activities of the male and the female must be constantly observed. Forecasts of the flowering periods must be issued during the stages from jointing to young panicle differentiation (forecasting methods can be based on the time of young panicle differentiation or the

leaf age). If it is forecasted that the flowering periods may not meet, the flowering periods must be adjusted. Different methods should be used to adjust the flowering periods according to different conditions. During the early and middle periods of young panicle differentiation, partial application of nitrogenous fertilizers and deep cultivation will stimulate tillering and delay heading and flowering. During the latter period of young panicle differentiation and the beginning period of heading, spraying with 20 ppm "920 (50 jin per mu) or the denial of water can be used to stimulate early heading and flowering. Experiments show that spraying "920" at the beginning period of heading can cause heading to occur 2 to 3 days earlier. Since the male is more sensitive to water, good results can be obtained by early drying or delaying irrigation in the field of the males. If all of the above methods fail to adjust the flowering periods properly and the flowering periods still will not meet, then measures such as removing the bract and panicles can be used to adjust the flowering periods.

2. Missing of the Flowering Times and Their Adjustments

Missing of the flowering times refers to the difference in flowering time when the flowering periods do coincide. Observations by the Cooperation and Coordination Group for Paddy Rice Heterosis Utilization Research of Hubei Province indicate during the one day of flowering of the "three lines" of paddy rice, the sterile-free line's flowering is the most stable. The speed of flowering and the flowering peak are clearly recognizable and the duration of flowering is short and concentrated. The restorer line is less stable and the sterile line's flowering speed is the most unstable; flowering is scattered and the duration is long. Since the flowering peak of the restorer line and the sterile-free line occurs sooner than that of the sterile line, the times of flowering often do not coincide. But, because the flowering habit of the sterile line is controlled by genes in the protoplasm, it is rather difficult to adjust this flowering habit by cultivational means. At present, selective cultivation of sterile lines with earlier flowering peaks or selective breeding of restorer lines with later flowering peaks may be the key to increasing the yield in fields of hybrid rice seed propagation and cultivation and propagation of percent sterile lines.

Although missing of the flowering times affects the yield of seed for propagation and cultivation and propagation of sterile lines to a very great degree, in practice the masses have created many methods to increase the fruiting percentage and to facilitate pollination. These methods have brought about definite increases in production. They are introduced below:

(1) Spraying water to delay the flowering time of the restorer line or the sterile-free line (all called the male): Experiments conducted by the Hubei Mianyang Middle School (1977) showed that spraying the males once or twice (separated by 0.5 to 1 hour) when the dew has just evaporated and the spikelets have just flowered can delay the flowering time of the males, facilitate the meeting of the flowering times and increase the fruiting percentage.

(2) Cutting away the flag leaf to facilitate pollination: In general, cutting away the flag leaves of the male and female at the beginning of heading and the flowering peak periods can facilitate dissemination of pollen by the male and pollination by the female and increase the fruiting percentage by 3 percent and the yield by 20 percent. The flag leaves should be cut away on sunny days after the dew has dried to facilitate curing of the wound and preventing bacteria from entering.

(3) Opening the bract: The bract can be opened when the panicle has emerged 1/3 to 1/2 by removing the leaf sheath from the flag leaf. Opening the bract not only facilitates solving the problem of enfolding of the neck of the sterile line so that spikelets at the bottom part of the female panicles can be exposed but also facilitates pollination and causes the flowering time of the sterile line to occur earlier and the flowering to be more concentrated. This is one of the effective measures to increase the fruiting percentage of the sterile line and increase the yield.

(4) Spraying "920": At the time when the flag leaf is being cut away, spraying the sterile line with 15 ppm of "920" will not only reduce the degree of enfolding of the neck but also cause the flowering time of the female to occur earlier and concentrate the occurrence of flowering. In general this can increase the fruiting percentage by 3 percent.

(5) Cutting off the main panicle of the male that has flowered: Removing the panicle of the main stem of the male after it has flowered facilities development of tiller panicles during the latter part of growth, reduces degeneration of spikelets, increases the amount of pollen of the male and extends the flowering period of the male.

Experiments conducted by the Yiyang County Agricultural Science Institute of Hunan Province (1976) illustrating the results of the above methods are listed and explained in tabular from (See Table 76).

3. Enfolding of the Neck and How to Overcome It

Enfolding of the neck is a phenomenon occurring on some of the sterile line varieties presently being used. The phenomenon is the failure of 1/5 of the panicle to emerge, preventing a part of the spikelets from flowering, pollination and fruiting and constitutes another cause of a low fruiting percentage. Studies indicate enfolding of the neck is controlled by the genes in the protoplasm. Thus, complete elimination of this problem must be done through breeding. However, opening the bract and spraying "920" are effective to a certain degree (See Table 76 and foregoing text).

In general, there are many causes of empty and semi-filled grains of paddy rice. There are internal causes and external causes (such as temperature, fertilizers, moisture and light). At present under the conditions of cultivation of our nation's double season rice (especially triple cropping) the effects of temperature are generally great but there are exceptions. When the temperatures are suitable, the techniques of fertilization or management

Table 76. Experimental Results of Different Treatments in the Cultivation of Sterile Lines

处 (a) 理	每亩成穗数 (b)(万)	(d)结实情况			产量比较 (g)	
		每(c)穗总粒数	其(e)中实粒数	结实率 (%) f	斤/亩 (h)	增产 (%) (i)
不育系剥苞 (j)	13.5	106.3	23.5	21.7	145.8	26.6
不剥苞 (k)	11.25	107.0	21.5	20.1	110.4	
剪除父母本剑叶 (l)	12.25	109.9	21.5	21.1	125.0	30.0
不剪剑叶 (m)	11.25	101.4	18.2	17.9	87.5	
剪除父本已扬花主穗 (n)	11.75	100.4	22.5	22.4	106.3	26.1
不剪主穗 (o)	10.25	106.7	17.1	16.6	83.3	
不育系喷"九二〇" (p)	11.25	117.7	27.3	23.1	114.6	14.6
不喷"九二〇" (q)	10.25	112.1	22.0	19.6	100.0	

Remark: Experimented combinations: Erjiunan No 1 sterile line x sterile-free line. Information listed are characteristic of sterile line.

Key:
- (a) Treatment
- (b) Number of panicles formed per mu (10,000)
- (c) Total number of grains per panicle
- (d) Fruiting Conditions
- (e) Number of filled grains
- (f) Percentage of fruiting (%)
- (g) Comparative Yield
- (h) jin/mu
- (i) Increase in yield (%)
- (j) Bract of sterile line removed
- (k) Bract not removed
- (l) Flag leaves of male and female removed
- (m) Flag leaves not removed
- (n) Flowered main panicle of male removed
- (o) Main panicle not removed
- (p) Spraying "920" on sterile line
- (q) "920" not sprayed

of irrigation and mushiness of the field may become the major problems. Thus, we must constantly and skillfully analyze the major problems causing empty and semi-filled grains of paddy rice and stimulate their conversion to full grains. We must exercise positive measures to reduce the percentage of empty and semi-filled grains and create higher yields from the [already] high yields of paddy rice.

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CHAPTER 6. GROWTH CHARACTERISTICS OF PADDY RICE VARIETIES

China is an expansive land and one of the places of origin of paddy rice. China has a rich resource of paddy rice varieties. Incomplete statistics indicate there are over 40,000 different varieties suitable for different regions and different seasons. Under our nation's planned socialist economy and the superior social system of the people's communes, reasonable utilization, distribution and combination of early, intermediate and late rice and their early, intermediate and late maturing varieties are important aspects in discovering the potentials for increasing production without too much labor and cost. Reasonable utilization, distribution and combination of paddy rice varieties are based upon profound understanding of the growth characteristics of paddy rice and of the various varieties.

I. Growth Characteristics of Paddy Rice

The development of paddy rice, after a period of vegetative growth, gradually changes into reproductive growth via a series of complex changes and under definite conditions. The transition is called development. The development of paddy rice is clearly manifested by a qualitative change in the apical point at the tip of the stem (meristem).

The meristems of paddy rice begin differentiating into the leaf primordia but when the paddy rice plant grows to a certain stage the meristems stop differentiating into the leaf primordia and change to differentiating into young panicles. The time of the qualitative change of the meristems of paddy rice is very important to planting paddy rice well and realizing stable and high yields. This is because without such a qualitative change the paddy rice plant will not be able to change from vegetative growth to reproductive growth. Remaining for a long period in the tillering stage will only allow the paddy rice to grow straws but not grains. If such qualitative change takes place too early the paddy rice plant will only be able to tiller and form young panicles under rather poor vegetative conditions, yielding "small panicle heads" (the number of grains per panicle is small), seriously affecting yield. If this qualitative change takes place too late the paddy rice plant will not be able to achieve full heading within the safe heading stage, yielding "raised panicle heads" (an abundance of empty and semi-filled grains), and even yielding no grains. Thus, to achieve reasonable distribution and

good combinations of paddy rice varieties and to produce stable and high yields, the causes of the qualitative change in the meristems of paddy rice and the conditions which cause the change to take place late or early must be understood. This is the problem concerning the characteristics of paddy rice development.

A. Sensitivity to Temperatures, Sensitivity to Light and Vegetative Growth Characteristics of Paddy Rice

Whether the qualitative change in the meristems of paddy rice occurs and the time of such a change are not only genetically determined but also to a large degree determined by environmental conditions. There are three main factors controlling the occurrence and the time of occurrence of such qualitative change. One is the amount of vegetative growth of the paddy rice plant itself, the second is temperature and the third is the duration of light.

Paddy rice originated in the swampy regions of the tropical and the subtropical zones. In those zones, paddy rice germinates in spring, completes its development at the end of summer and the beginning of autumn when the temperatures are high and the duration of sunshine is shortening. This is when the panicles begin to grow. The panicles head and bear fruit in autumn. In this lengthy and systematic process of development, the high temperatures and short duration of sunshine in the southern tropical zone and the subtropical zone have tamed the paddy rice and formed the basic developmental characteristics of the requirements for "high temperatures and short sunshine." Thus, shortening the daily duration of sunshine to below 12 hours under high temperatures will stimulate growth of all varieties of paddy rice to different degrees and cause the growth of panicles and heading of panicles to occur earlier, thus shortening the period of growth (The qualitative change of the meristems occurs early). However, indepth studies indicate that prior to qualitative change of the meristems, the vegetative growth period can be further divided into a basic vegetative growth period and a variable vegetative growth period. The basic vegetative growth period cannot be shortened by high temperatures and a lessening daylight period. High temperatures and short duration of sunshine are the bases for the growth that takes place during this period. The variable vegetative growth period, however, can be shortened by high temperatures and short duration of sunshine.

The variable vegetative growth period can be further divided into two parts: One is the period which can be shortened by high temperatures and the other period which can be shortened by short duration of sunshine (photoperiods) (Diagram 65).

Different paddy rice varieties have very different sensitivities to light, sensitivities to temperatures and basic vegetative growth periods because of different temperatures and conditions of light and natural and human selection at the place of origin. We are able to select the most decisive characteristics and classify the paddy rice varieties accordingly into three major categories (Table 77).

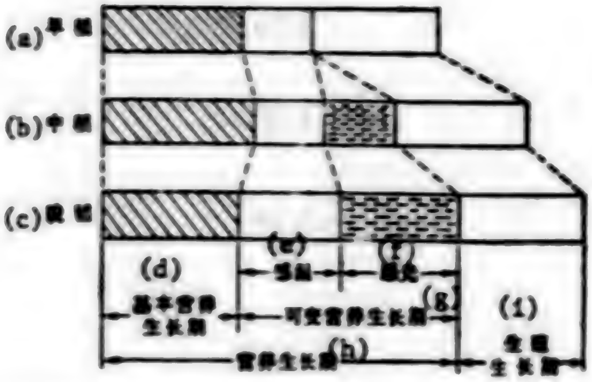

Diagram 65. Sensitivity to Temperatures, Sensitivity to Light and Basic Vegetative Growth Periods

Key: (a) Early rice
(b) Intermediate rice
(c) Late rice
(d) Basic vegetative growth period
(e) Sensitive to temperatures
(f) Sensitive to light
(g) Variable vegetative growth period
(h) Vegetative growth period
(i) Reproductive growth period

Table 77. Vegetative Growth Period, Basic Vegetative Growth Period and Variable Vegetative Growth Period of Paddy Rice (Jiangsu Provincial Agricultural Science Institute, 1973)

Type	Variety	营养生长期 (a) (天)	基本营养生长期 (b) (天)	可变营养生长期 (c) (天)	在可变营养生长期中 (d): 为经高温所缩短(天) (e)	为短日照所缩短(天) (f)
Early rice	Erjiunan No 2	61	44	17	18	— 1
	Ainanzao No 1	65	43	22	23	— 1
	Erjiuqing	67	44	23	24	— 1
	Ainanzao 39	70	44	26	27	— 1
	Guanglual No 4	79	51	28	28	0
Intermediate rice	Kezi No 6	110	76	34	11	23
	Nonken27	102	53	49	30	19
	Guihuahuang	111	39	72	28	44
	Jinyin 15	106	46	60	26	34
Late rice	Huxuan 19	109	44	65	34	31
	Jianong 482	112	46	66	38	28
	Nonghu No 6	122	45	77	30	47
	Nongken 58	122	45	77	32	45
	Sugeng No 2	120	43	77	32	45
	Yuhong No 1	126	43	83	38	45

Key: (a) Vegetative growth period (days)
(b) Basic vegetative growth period (days)
(c) Variable vegetative growth period (day)
(d) During the variable vegetative growth period
(e) Shortened by high temperatures(days)
(f) Shortened by short duration of sunshine (days)

1. Varieties that are strongly sensitive to temperatures

The occurrence and time of qualitative change in the meristems are mainly regulated by temperature. When the temperature rises to the range of suitable temperatures, differentiation of panicles visibly occurs earlier and the heading period is visibly shifted to an earlier time. Varieties that are strongly sensitive to temperature include Erjiuqing and Quangluai No 4.

2. Varieties that are strongly sensitive to light

The occurrence and time of qualitative change in the meristems are mainly regulated by photoperiods. The beginning period of young panicle differentiation and the period of heading occur earlier when the daily duration of sunshine is shortened. Such varieties include "Nongken No 58" and "Nonghu No 6."

3. Varieties with a strong basic vegetative growth

The qualitative change in the meristem is mainly regulated by the amount of basic vegetative growth and is relatively less sensitive to high temperatures and photoperiods. Whether the plant of these varieties is planted early or late, the vegetative growth period's relative change is small. Such varieties include "Kezi No 6" (i.e., "IR-8").

The above is a general classification only. The actual situation is much more complex and often may characteristics may coexist in the same variety such as one having both a strong sensitivity to light and a strong sensitivity to temperature (for example, "Guihuahuang") and the variety having both a strong vegetative growth and a medium sensitivity to light (for example, "Nongken 57")....

B. The Phenomenon of Photocycles

1. The Reaction to photocycles of Paddy Rice

Some of the paddy rice varieties that we usually cultivate do not have any exact sowing periods and may be sown "earlier and earlier." But there are also some varieties that can only be cultivated as late rice, such as the late rice varieties of Guangdong. Whether sown early or late, their young panicles will generally differentiate only after September and will head only after October, as the farmer's saying says: "Three days after October 8, the late and the early hit the mark together." Some late rice varieties planted in the Chang Jiang River valley such as "Nongken No 58" also manifest similar characteristics (Table 78), that is, even if the sowing periods are three months apart, the beginning period of young panicle differentiation will only vary by a month and a half, and young panicle differentiation and heading will begin only after June 21 when the duration of sunshine shortens. What are the reasons?

Experiments conducted by the former Huadong Agricultural Science Institute Crop Physiology Laboratory 1955) showed that when paddy rice varieties originally growing in different regions at different latitudes were planted in Nanking, the paddy rice varieties that originally grew in the north were able to head under long durations of light and even under 24 hours of continuous light. However, late rice varieties of the south were only able to head when the photoperiod lasted less then 14 hours (Table 79). What is the reason for this difference?

Table 78. The Full Growth Period, Heading Period and Young Panicle Differentiation Period of "Nongken : > 58" Sown at Different Periods (Hunan Academy of Agricultural Sciences, Agricultural Crop Teaching and Research Group, 1975)

(a)	(b)	(c)	(d)	(e)
1	3/25	7/6	8/7	173
2	4/15	7/9	8/12	158
3	5/6	7/20	8/23	144
4	5/25	8/1	9/3	138
5	6/5	8/7	9/8	130
6	6/15	8/13	9/11	123
(f) 7	6/25	8/20	9/16	113
(f)	92	46	40	59

Note: Experiment was conducted at Changsha.

Key: (a) Number
(b) Sowing time (month/day)
(c) Beginning time of young panicle differentiation (month/day)
(d) Heading time (month/day)
(e) Full growth period (days)
(f) Difference between the number of days of No 1 and No 7.

Table 79. Heading of Paddy Rice Varieties of Different Origins Under Different Photoperiods

(a)	(b)	(c)	(d)	(u) (e)	(u) 8 (f)	(u) 12 (f)	(u) 14 (f)	(u) 16 (f)	(u) 24 (f)	(g)
(h)	(i)	(j)	43°	7/10	7/10	7/10	7/8	7/7	7/9	8~24
(k)	(i)	(l)	40°	7/26	7/29	7/30	7/31	8/1	8/11	12~14
(m)	(n)	(o)	32°	9/3	7/5	7/7	8/10	9/21~11/1	9/12	8~12
(p)	(q)	(r)	31°	9/5	7/21	7/17~24	9/1	(v)	(v)	8~12
(s)	(n)	(t)	20°	—	7/9~11	7/20~29	(v)	(v)	(v)	8

Note: Experiment was conducted in Nanjing.

Key: (a) Variety
(b) Type
(c) Origin
(d) Latitude of place of origin (°N)
(e) Natural light
(f) hours
(g) Most suitable photoperiod (hours)
(h) Fuguo
(i) early geng
(j) Hokaido Japan
(k) Xiongyue 5.2.5
(l) Liaoning, Xiongyue
(m) Huke rice
(n) late xian

Key [Continued]

(o) Nanjing
(p) Laolaiqing
(q) late geng
(r) Shanghai
(s) Baihuaqi
(t) Haikou
(u) Date of heading under different photoperiods
(v) does not head

Studies indicate that at different regions and in different seasons of the year, the duration of light and darkness of a day often changes in a cyclic fashion (Diagram 66 and Table 30). After March 20, the duration of light gradually increases and reaches the longest duration on June 21. After June 21 the duration gradually shortens. Plants, in a long and systematic growth period, have acquired the habit of reacting to the stimulus of the cyclic nature of the duration of light and darkness in flowering and fruiting. The effect of the alternation of the different lengths of duration of day and night upon flowering and fruiting of plants is called photoperiodism of plants.

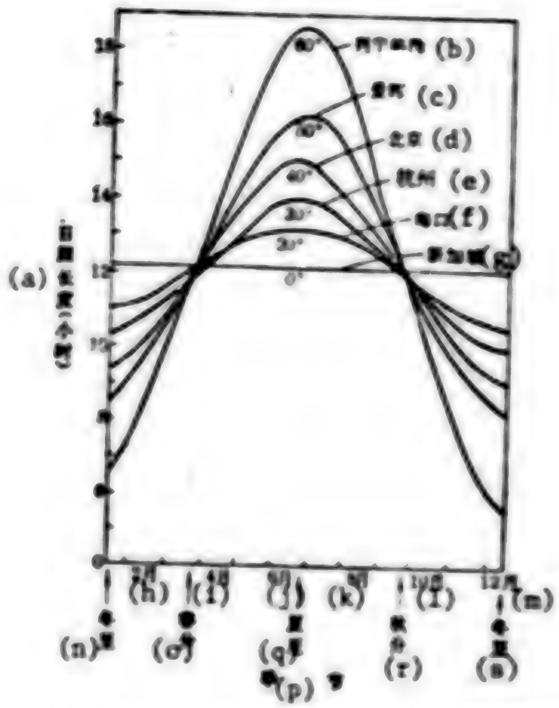

Diagram 66. Changes in Duration of Sunshine in Different Seasons and at Different Latitudes.

Key:
(a) Duration of sunshine (hours)
(b) Leningrad
(c) Aiguu
(d) Beijing
(e) Hangzhou
(f) Haikou
(g) Singapore
(h) February
(i) April
(j) June
(k) August
(l) October
(m) December
(n) December 21
(o) March 20
(p) The seasons
(q) June 21
(r) September 23
(s) December 21

Table 80. Changes in Duration of Sunshine During the Four Seasons at Localities With Different Latitudes in China (hour:minute)

地点 (a)	纬度(北纬) (b)	春分 (c)	夏至 (d)	秋分 (e)	冬至 (f)
爱g珲	50°	12:20	16:22	12:14	8:04
北h京	40°	12:10	15:01	12:11	9:12
上i海	31°	12:08	14:11	12:07	10:07
杭j州	30°	12:09	14:05	12:07	10:13
广k州	23°	12:08	13:28	12:06	10:43
海l口	20°	12:08	13:20	12:08	10:56

Key:
(a) locality
(b) latitude N
(c) March 20
(d) June 21
(e) September 23
(f) December 21
(g) Aihui
(h) Beijing
(i) Shanghai
(j) Hangzhou
(k) Guangzhou
(l) Haikou

Based on differences in the need for sunlight of various plants to flower, plants can be generally divided into three types, the short-day type, long-day type and the intermediate (day-neutral) type. It can be seen from Table 79 that flowering of paddy rice speeds up under shorter daylight. Flowering will not be possible or flowering will be delayed when the duration of daylight is too long. Thus paddy rice is a short-day plant. Within 24 hours of a day and night, the most suitable duration of daylight for paddy rice to flower and fruit and especially for the paddy rice varieties originating from the South, is one that lasts for less than 12 hours and even shorter than 8 hours. This is a manifestation of the adaptation to environmental conditions formed during the lengthy and systematic process of the development of the paddy rice plant. It can be seen from Table 79 that paddy rice varieties that originate from the South have a stricter demand upon short daylight (in other words, southern varieties are more sensitive to daylight). Paddy rice as a short-day plant will not be able to flower when the duration of daylight surpasses a certain length. The maximum duration of daylight for flowering is called the critical day or the critical photoperiod. When the duration of light lasts a certain length of time which is must suitable for heading and flowering, that length of daylight is called the most suitable photoperiod (Table 79). The critical photoperiod of most of the short-day paddy rice varieties of the Chang Jian valley is between 12.5 and 13.5 hours and the most suitable photoperiod is 8 to 12 hours. Further experiments proved that the major factor inducing the short-day paddy rice to head and flower is not the short daylight period but the long period of darkness. Experiments showed that if a light of several dozen meter-candles is supplied for 5 to 10 minutes during the lengthy period of darkness, this is sufficient to stimulate short-day rice to flower (In general, paddy rice will begin to react in a light of between 8 and 20 meter-candles). A light

of between 30 and 50 meter-candles is equivalent to daylight, thus breaking the darkness. The Paddy rice plant will react as if the daylight period were long and the period of darkness were short and will not be able to head and flower (Diagram 67). Thus, paddy rice varieties with a strong sensitivity to light require longer continued darkness and within a definite limit, the longer the darkness the earlier a plant of those varieties will flower. Of course, the longer the period of darkness the better is not necessarily true. Experiments showed that a definite period of daylight must exist before a lengthy period of darkness. This is very important to the formation of spikelets. If the photoperiod (daily duration of daylight) is shorter than 2 hours, young panicles will not differentiate and the plant will not head and flower (Diagram 68).

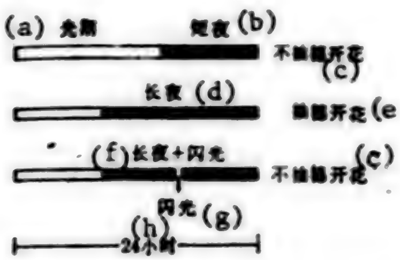

Diagram 67. Effect of Interruptive Flashing Light During Period of Darkness Upon Heading and Flowering of Short Day Paddy Rice Varieties

Key:
- (a) photoperiod
- (b) short night
- (c) does not head and flower
- (d) long night
- (e) Heads and flowers
- (f) Long night + flashing light
- (g) Flashing light
- (h) 24 hours

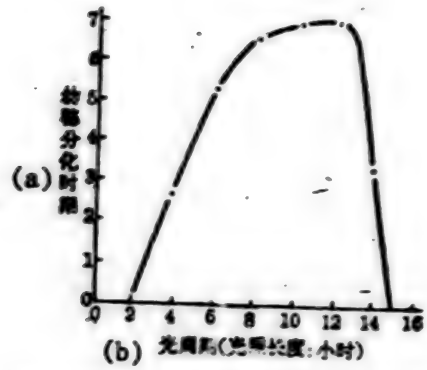

Diagram 68. Flowering Reaction of Paddy Rice Under Different Lengths of Duration of Light (K. Ikeda, 1974)

Note: (1) The variety is "Nonglin 18," a variety that is strongly sensitive to light.
(2) Results after 30 days of treatment
(3) Indicators at time of young panicle differentiation

0. Tillering has not begun
1. First branch tillers
2. Second branch tillers
3. Early period of differentiation of primordium of spikelet
4. Latter period of differentiation of primordium of spikelet
5. Period of formation of reproductive cells
6. Prophase of meiosis.
7. Anaphase of meiosis.

Key: (a) Period of young panicle differentiation
(b) Photoperiod (duration of light: hours)

2. Photoperiodism of Paddy Rice and Other External Conditions

The photoperiodism of paddy rice varieties is based on a definite level of heat and is closely related to temperature (especially nighttime temperature). Experiments showed that the number of days necessary to induce young panicle differentiation of late geng "Laolaiqing" placed in the dark for 14 hours (10 hours of light) a day from the time of sowing to the beginning period of young panicle differentiation was 25 days with a temperature of between 25°C and 30°C and 51 days with a temperature of between 15°C and 20°C. With a temperature of between 6°C and 13°C, young panicles did not differentiate.

The duration of reaction of paddy rice to the photoperiods and the number of photocycles are related to the characteristics of the varieties and external environmental conditions. Induction of panicle differentiation of most of the varieties with a strong sensitivity to light in the Chang Jiang Valley requires from 5 to 24 photoperiods each lasting 10 hours (i.e., a

10-hour day and a 14-hour night for 5 to 24 days and nights) with appropriately high temperatures, counting from the time 15 to 20 days after sowing when the plant is in the 4 to 5 leaves stage. In general, xian rice requires less number of photocycles while geng rice requires more. Also, the plant's reaction to the photocycle is faster when the plant is in the 7 leaves stage. As the plant grows older the pace at which young panicle differentiation is induced by the photocycles becomes faster. Experiments showed that the late geng "Nongken No 58" began to be sensitive to light during the leaf age of the 4 (Table 81, treatments 2.4.6.8). Over 10 photocycles of short photoperiods (10-hour day) are required to induce the young panicles to begin differentiation, a duration covering the growth period of three leaves. If the plant is subjected to short photoperiods after the 4th leaf period, then as the leaf age increases, a lesser number of photoperiods are required but heading will be delayed. It can be seen from treatments 7 and 8 in Table 81 that short photoperiods will induce the young panicles to differentiate both prior to the time of young panicle differentiation and after the young panicles have begun to differentiate. After the young panicles have begun to differentiate, the photocycle must span the period of growth of 1 to 2 leaf ages, otherwise the photocycle is insufficient to successfully induce early heading and flowering.

Table 81. Number of Photocycles and Light Sensitive Leaf Age of "Nongken No 58" (Central China (Huazhong) Agricultural College, Agriculture Department, 1976)

(a) 处理代号	(b) 10小时短日处理		(e) 幼穗分化始期 (月/日)	(f) 短日处理开始至幼穗分化的叶龄及日数		(h) 抽穗期 (月/日)	(i) 抽穗期提早日数
	(c) 叶龄	(d) 日数		(c) 叶龄	(g) 日数（光周期次数）		
1	1~4.5	11	9/4	—	—	10/3	(j) (对照)
2	1~10	30	8/5	1~7	18	9/6	27
3	2~5	11	9/4	—	—	10/3	0
4	2~10	28	8/5	2~7	16	9/6	27
5	3~6	11	9/4	—	—	10/3	0
6	3~10	25	8/5	3~7	[illegible]	[illegible]	27
7	4~7	10	8/6	4~7.3	10	10/3	0
8	4~10	[illegible]	8/6	4~7.3	10	9/6	27

Key:
(a) Treatment No.
(b) 10-hour short days
(c) Leaf age
(d) days
(e) Beginning period of young panicle differentiation (month/day)
(f) Leaf age and number of days from the beginning of short day treatment to young panicle differentiation
(g) days (photocycle)
(h) heading time (month/day)
(i) Heading time number of days earlier
(j) (control)

In addition, the leaf age at which the plant becomes sensitive to light is probably related to the place of origin. It is generally believed that varieties with a very strong sensitivity to light originating in low latitude regions begin to become sensitive to light at an older leaf age. For example, "IR-8" begins to become sensitive to light at a leaf age of 7 leaves. At this time it requires 20 or more 10-hour days for panicles to differentiate. "Laolaiqing" (Shanghai), a variety with a sgrong sensitivity to light originating in a middle latitude region, begins to become sensitive to light at a leaf age of 5 leaves. At this time 15 short photoperiods are required to induce panicle differentiation. "Nongken No 58," a variety that is sensitive to light originating in a high latitude region, begins to become sensitive to light at a leaf age of only 4 leaves. At this time 10 10-hour days are required to induce panicle differentiation.

3. The Chemistry of the Reaction to Photoperiods

How do photoperiods cause the meristems to change from differentiation of leaves to differentiation of young panicles? Studies in recent years indicate that leaves, especially tender leaves, are the main organs to react to photoperiodism. Under definite temperatures and during short photoperiods, a substance called "florigen" is transported to the meristems by the active cells of the phloem causing the meristems to differentiate into young panicles. But what is the "florigen" that causes the paddy rice meristems to differentiate into panicles? It is not clearly understood at present. The formation of florigen is probably related to some substances called phytochromes.

Phytochromes have a molecular weight of 60,000 and contain an open chain of four pyridine rings of conjugate base protein similar to enzymes. The phytochrome appears blue or blue-green and is extremely sensitive to light. There are two types of phytochromes. One is the phytochrome P660 with the ability to absorb a light of a maximum wave length of 660 millimicrometers (1 millimicrometer equals 1 millionth of a micrometer). The other is phytochrome P730 with the ability to absorb infrared light of a maximum wave length of 730 millimicrometers. Both of these phytochromes exist in the body of plants and are interconvertible:

$$\text{Phytochrome P660} \underset{\text{infrared light (730 mm) or darkness}}{\overset{\text{red light (66 mm) or white light}}{\rightleftarrows}} \text{phytochrome P730}$$

In the light, the main form of phytochrome existing in the body of the plant is P730. When the plant is placed in the dark, P730 is gradually converted to P660. It takes 8 to 10 hours for phytochrome P730 to convert itself to photochrome P660. If the darkness is pierced by flashing light, this conversion will not be completed.

It has been proven now that P730 is active and the formation of "florigen" in the plant is related to the ratio of P730/P660. Short-day-crop paddy rice requires a low P730/P660 ratio. As the hours of daylight of each day shorten (and the length of darkness lengthens), P660 increases and the ratio of P730/P660 becomes small, causing "florigen" to form which induces the

panicle to differentiate or stimulates panicle differentiation to occur earlier. As the hours of daylight of each day lengthens (the period of darkness shortens), P 730 increases and the ratio of P730/P660 increases, delaying panicle differentiation. If the hours of daylight of each day increase and surpass the critical photoperiod (or flashing light during the period of darkness), conversion of P730 to P660 cannot proceed easily, causing the paddy rice varieties strongly sensitive to light to remain in the state of vegetative growth for a long time unable to enter the young panicle differentiation stage. Long-day-crops (such as wheat) require a high P730/P660 ratio. As the hours of daylight of each day increase (period of darkness shortens), P730 increases and the ratio of P730/P660 increases, causes formation of "florigen" which induces or stimulates panicle differentiation to occur earlier. As the hours of daylight of each day shorten (the period of darkness lengthens), P660 increases and the P730/P660 ratio lessens which is unfavorable to formation of "florigen" and which prevents or delays panicle differentiation.

In general, the physiological basis for paddy rice's sensitivity to light involves stimulation of the phytochromes in the leaves by photoperiods (lengthy period of darkness) when the paddy rice plant has a leaf age of between 4 and 5 leaves. After a definite period, the formation of "florigen" which is transported to the meristems, causes the meristems to undergo a qualitative change for panicle differentiation. Since the places of origin of the varieties have different lengths of daylight and the varieties are subject to different natural and human selection, strong and weak sensitivities to light have developed during the long periods of systematic development of the paddy rice varieties. The comparative study conducted by Wu Guanghan [0720 0342 0583] et al (1957) of the former Huadong Agricultural Science Institute compared 900 representative varieties of paddy rice. He classified the photosensitivity of China's paddy rice varieties into five categories of extremely weak (Type I), weak (Type II), neutral (Type II), strong (Type IV) and extremely strong (Type V) according to the length of the critical photoperiod, range of the lengths of photoperiods of different heading periods, and differences in the number of days of delayed heading periods under long daylight and short durations of darkness (Table 82).

C. Effects of Temperature on Successful Flowering

Temperature is a factor that often exerts its effects during the life of the paddy rice. It first serves as a condition of growth and growth is the basis for development. On the other hand, temperature also affects development and completion of a certain stage of development which requires a certain lowest total amount of heat. But the effect of temperature upon successful flowering does not begin at the time the seeds germinate. Experiments indicate the effect of high temperatures upon successful flowering begins at the time of the 4th leaf period. High temperatures occurring before this time do not visibly stimulate earlier change of the meristems of paddy rice varieties strongly sensitive to temperatures. Thus, the effect of high temperatures upon successful flowering of some paddy rice

Table 82. Classification of the Sensitivity to Light of China's Paddy Rice Varieties

(a)	(b)	(c)	(d) (e)	(d) (f)	(d) (g)	Major Regions of Distribution
I	(b)	(h)	—	0~12	—	Heilongjiang, Taiwan Province (double season early and late rice dual purpose variety)
	(i)	(h)	—	0~12	—	Provinces of South China (first season rice), provinces of Central China (early, intermediate rice), Yunnan-Guizhou Plateau (first season rice or early rice)
II	(b)	(j)	13.5~18.0	13~30	13.5~18.0	Jilin, Xinjiang, Gansu, northern Hebei, Jiangsu, Jiangxi (very early maturing geng rice).
	(i)	(j)	—	13~30	9.5~13.5	Provinces of southern China (first season rice), provinces of Central China (early, intermediate rice), Yunnan-Guizhou Plateau (first season rice or early rice).
III	(b)	(k)	13.5~18.0	>30	13.5~18.0	Central Hebei, Jiangsu (early maturing intermediate geng rice)
	(i)	(k)	—	>30	9.5~18.0	Sichuan, Yunnan, Guizhou (single season early, intermediate rice, double cropped early rice).
IV	(b)	(l)	12.5~13.5	>30	12.5~18.0	Taihu Area of Jiangsu and Zhejiang, Shanghai Municipality (single season late rice).
	(i)	(l)	12.5~13.5	>30	12.5~18.0	Provinces of Central China (single season late rice), Yunan-Guizhou Plateau (single season late rice).
V	(b)	(m)	11.5~12.5	>30	11.5~18.0	Provinces in southern China and Yunnan (second season geng and nuo rice)
	(i)	(m)	11.5~12.5	>30	11.5~18.0	Provinces of southern China and Yunnan (second season rice).

Key:
(a) Type
(b) geng
(c) Sensitivity to light
(d) Characteristic reactions to different lengths of daylight
(e) Critical photoperiod (hours)
(f) Number of days heading was delayed by a photoperiod of between 9.5 and 18 hours
(g) Photoperiod of different heading periods (hours)
(h) extremely weak
(i) xian
(j) weak
(k) neutral
(l) strong
(m) extremely strong

varieties that are strongly sensitive to temperatures must be a genetic characteristic formed during the systematic development of paddy rice. Temperature, like photoperiodism, affects the time of the qualitative change of the meristems.

The strength or weakness of the sensitivity to light of paddy rice is manifested by a delay in sowing because the growth period visibly shortens when the temperatures rise. Experiments indicate varieties that are strongly sensitive to temperatures can shorten their growth period by over 30 percent under higher temperatures whereas varieties that have a weak sensitivity to light can shorten their period of growth by 20 percent or more (Table 83). Shortening of the period of growth is mainly a shortening of the vegetative growth period prior to young panicle differentiation. This period of vegetative growth is shortened by over 50 percent in varieties that are strongly sensitive to light and by over 40 percent in varieties that have a weak sensitivity to light.

Experiments conducted by the Huazhong Agricultural College Crop Cultivation Teaching and Research Group (1975) showed that the sensitivity of paddy rice varieties to temperature can be expressed by a temperature sensitivity index. The temperature sensitivity index refers to the percentage reduction of the entire period of growth by a rise of 1°C in the daily average temperature based on comparison of the earliest sowing time of a particular variety in a locality when the growth period has been shortened the most number of days. Their experiments indicated that the temperature sensitivity index of "Xiangaizao No 8," "Hunanzao No 1" and "Huaai No 15" is all above 6 percent and therefore these varieties have the strongest sensitivity to temperatures. The temperature sensitivity index of "Guangluai No 4" and "Erjiuqing" is above 5 percent but below 6 percent and their sensitivity to temperatures is the second strongest. The temperature sensitivity index of "Wenge" and "Zhulianai" is both below 5 percent and are regarded as varieties with weaker sensitivity to temperatures (Table 83).

Because weather factors affect the length of the growth period greatly and because the difference between the growth periods under different temperatures and of different years is great, the sensitivity to temperatures of the varieties is often expressed by total cumulative temperature, flexible cumulative temperature and effective cumulative temperature in units of "degree-day" (Table 84).

It can be seen from Table 84 that using the growth period to indicate the effect of temperature upon successful flowering results in a relative deviation of above 8 percent. Using the flexible cumulative temperature to indicate the effect of temperature upon successful flowering results in a relative deviation of only 1.8 percent to 5.7 percent. Using the effective cumulative temperature to indicate the effect of temperature upon successful flowering results in the smallest relative deviation. In particular, the time of change of the meristems of plants of the paddy rice varieties that are strongly sensitive to temperatures but have a weak sensitivity to light is controlled by the effective cumulative temperatures to a large extent.

Table 83. Comparison of the Sensitivity to Temperatures of Several Early Rice Varieties (Huazhong Agricultural College, Crop Cultivation Teaching and Research Group, 1975)

品种 (a)	播种期 (b) (月/日)	(c) 从播种到幼穗分化				全生育期 (h) (天)	(i) 生育期缩短		(j) 全期日平均温度 (℃)	(k) 平均温度相差 (℃)	(l) 感温性		
		分化期 (d) (月/日)	日数 (e)	(f) 分化期缩短			天数 (g)	%			感温指数 (m) (%)	强弱 (n)	次序 (o)
				天数 (g)	%								
湘矮早8号	3/20 6/10	5/11 7/7	52 27	25	48.1	121 81	40	33.1	22.09 27.15	5.06	6.54	强 (w)	1
沪南早1号 (p)	3/20 6/10	5/18 7/8	59 29	30	50.6	126 87	39	30.9	22.38 27.13	4.74	6.52	强 (w)	2
华矮15号 (q)	3/20 6/10	5/15 7/3	56 23	33	58.9	116 79	37	31.9	21.98 27.21	5.28	6.04	强 (w)	3
广陆矮4号 (r)	3/20 6/10	5/17 7/5	58 25	33	56.8	124 89	35	28.2	22.22 27.16	4.93	5.72	次强 (x)	4
二九青 (s)	3/20 6/10	5/9 7/2	50 22	28	56.0	110 77	33	30.0	21.63 27.30	5.67	5.29	次强 (x)	5
温革 (t)	3/20 6/10	5/14 7/12	55 30	25	45.4	122 91	31	24.6	22.12 27.19	5.07	4.83	弱 (y)	6
竹莲矮 (v)	3/20 6/10	5/10 7/8	51 28	23	45.0	116 93	23	19.3	21.90 27.19	5.29	3.68	弱 (y)	7

Note: Sensitivity to temperature index is for every rise of 1°C in temperature. The percent is of the shortening of the entire growth period. The locality for experimentation was Wuhan.

Key:
(a) Varieties
(b) Sowing date (month/day)
(c) From sowing to young panicle differentiation
(d) Time of differentiation (month/day)
(e) Number of days
(f) Shortening of the period of the differentiation days
(g) days
(h) Total growth period (days)
(i) Shortening of the growth period
(j) Average daytime temperature throughout the period (°C)
(k) Average difference in temperature (°C)
(l) Sensitivity to temperatures
(m) Sensitivity to temperature index
(n) Strength
(o) Order
(p) Xiangaizao No 8
(q) Hunanzao No 1
(r) Huaai No 15
(s) Guangluai No 4
(t) Erjiuqing
(u) Wenge
(v) Zhulianai
(w) strong
(x) Second strongest
(y) weak

Table 84. Growth Period and Cumulative Temperatures of Different Early Rice Varieties Sown at Different Times (Central China (Huazhong) Agricultural College, Crop Cultivation Teaching and Research Group, 1975)

类型 (a)	品种 (b)	第一播期的生育期 (天) (c)	七期平均生育期 (天) (d)	标准差 (±) (e)	相对偏差 (%) (f)	感温性强弱 (g)	活动积温 (h) 七期平均 (日.度) (i)	标准差 (±) (e)	相对偏差 (%) (f)	有效积温 (j) 七期平均 (日.度) (i)	标准差 (±) (e)	相对偏差 (%) (f)
早熟 (k)	二九青 (l)	110	94.3	10.7	11.3	次强 (s)	2293.5	49.8	2.2	1347.2	22.8	1.7
	华矮15 (m)	116	96.6	11.6	10.1	强 (t)	2413.2	131.9	5.7	1407.5	69.2	4.9
中熟 (n)	竹莲矮 (o)	118	102.0	8.06	8.4	弱 (u)	2506.9	45.4	1.8	1469.5	76.8	5.2
	湘矮早8号 (p)	121	100.7	13.3	13.2	强 (t)	2671.4	142.6	5.7	1457.9	29.9	2.2
迟熟 (q)	广陆矮4号 (r)	126	105.4	10.1	9.6	次强 (s)	2605.8	153.6	5.7	1540.9	60.2	3.4

Note: Sown on seven dates: 3/20, 3/30, 4/10, 4/20, 4/30, 5/10, 6/10.

Key:
(a) Type
(b) Variety
(c) Growth period of first sown (days)
(d) Average growth period of the seventh sown (days)
(e) Standard deviation
(f) Relative deviation
(g) Sensitivity to temperatures strong weak
(h) Flexible cumulative temperatures
(i) Average of 7 periods (degree/day)
(j) Effective cumulative temperature
(k) Early maturing
(l) Erjiuqing
(m) Huaai 15
(n) Intermediate maturing
(o) Zhulianai
(p) Xiangaizao No 8
(q) Late maturing
(r) Guangluai No 4
(s) second strongest
(t) strong
(u) weak

Thus, the time of development of the meristems can be accurately predicted by effective cumulative temperatures. Data on six early xian varieties sown separately gathered by the Jiangsu Agricultural College, Crop Cultivation Teaching and Research Group (1972-1973) showed the number of days between sowing and full heading of each variety is very closely related to cumulative temperatures. When the correlation coefficient is between 0.93 and 0.98, the difference between the cumulative temperatures is also great (Table 85).

Table 85. Effective Cumulative Temperature (degree-days) of Several Early Xian Varieties for Each Period of Development

品种 (a)	播种至幼穗分化 (b)	(c) 播种至齐穗	(d) 播种至成熟
二九矮1号(e)	311	666	1068
矮南早1号(f)	363	730	1117
二九青 (g)	364	738	1160
矮南早39号(h)	422	784	1187
广陆矮4号(i)	456	868	1298
矮脚南特 (j)	451	880	1290

Remark: A temperature of 11°C is taken as the biological starting temperature to calculate effective cumulative temperatures.

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* Total cumulative temperature is the total of the actual temperatures of each day of the period of development. Flexible cumulative temperature is the total of the actual temperatures of each day of the period of development that are above the starting temperature. Effective cumulative temperature is the total of the temperatures of each day of the period of development above the starting temperature, i.e., the total of the differences between the actual temperature and the starting temperature for development.

** Correlation coefficient γ represents the correlation between two factors. When γ approaches 1, the correlation becomes closer.

Key:
(a) Variety
(b) Sowing to panicle differentiation
(c) Sowing to full heading
(d) Sowing to maturity
(e) Erjiulu No 1
(f) Ainanzao No 1
(g) Erjiuqing
(h) Ainanzao No 39
(i) Guangluai No 4
(j) Aijiaonante

II. Growth Characteristics of Early, Intermediate and Late Rice

Of the paddy rice presently being cultivated, only late rice still retains the developmental characteristics of the ancestors requiring high temperatures and short daylight. But, for several thousands of years via our nation's laboring people's economic and cultural interaction, paddy rice was introduced from our nation's south to the north. Due to the change in planting regions and seasonal changes, paddy rice was forced to survive under lower temperatures and longer sunshine periods. Under the new conditions a few plants underwent physical mutation and through human selection

and cultivation changed their developmental characteristics requiring "high temperatures and short daylight" to become early and intermediate rice. Thus, the early, intermediate and late rice varieties' developmental characteristics of today are not all the same. Grasping the developmental characteristics of each of them will benefit our efforts in reasonable utilization, distribution and combination.

A. Growth Characteristics of Late Rice

Late rice varieties all possess a weak basic vegetative growth but their sensitivity to light and temperature is high. Since late rice cultivated in the middle and lower reaches of the Chang Jiang Valley is subject to higher temperatures beginning from the time of sowing, the temperature for successful flowering is not limited and thus the length of the growth period of late rice varieties is affected mainly by the length of daylight. A photoperiod over 13.5 hours will prolong the period of growth and a photoperiod over 18 hours will prevent heading (Table 86).

Table 86. Sensitivity to Light of Late Rice Varieties (Jiangsu Provincial Agricultural Science Institute, 1973)

品 种 (a)	在不同光周期下从播种到抽穗的天数 (b)			
	自然光照 (c)	10小时光照 (d)	13.5小时光照 (e)	18小时光照 (f)
(g) 苏粳2号	101	67	90	未抽穗 (k)
(h)	106	67	85	未抽穗 (k)
(i) 农垦58	106	67	88	未抽穗 (k)
(j) 农虎6号	106	67	88	未抽穗 (k)

Key:
(a) varieties
(b) Number of days between sowing and heading under different photoperiods
(c) natural light
(d) 10-hour daylight
(e) 13.5-hour daylight
(f) 18-hour daylight
(g) Sugeng No 2
(h) Yuhong No 1
(i) Nongken 58
(j) Nonghu No 6
(k) No heading

In the middle and lower reaches of the Chang Jiang region, the growth period of late rice lasts between 150 and 170 days. This is because under natural conditions, late rice is subjected to overly long daylight after sowing. Panicle differentiation, heading and maturity are induced only

after the number of hours of daylight has lessened to a certain number. Actually, late rice does not require over 150 days to mature. Under conditions of high temperatures and short daylight, it will become like early rice requiring a very short period of growth. Thus, the change in the duration of natural daylight of the locality is the main reason determining the length of the growth period of late rice. If the late rice variety "Nongken 58" is planted in the Shanghai area and transplanted during the last ten days of May, it will not begin young panicle differentiation until the end of July or the beginning of August when the number of daylight hours lessens because its growth during the time of increasing daylight hours is hampered. It will mature at a time close to that of "Nongken 58" transplanted at the beginning of July. This can be described as "one sleeping early and the other sleeping late but both getting up at the same time." Thus, the same variety planted at different localities will have different lengths of growth. Sometimes even the same variety planted in the same locality will have different lengths of growth because of different sowing times. Since changes in the duration of daylight at one locality are basically the same year after year, the heading time of late rice over the years does not vary much, generally within a difference of 7 days.

Although late rice varieties belong to the type of plants that are highly sensitive to light, different varieties have different degrees of sensitivity to light which determine the length of the growth period of the different varieties. Thus, late rice varieties can be further divided into the early, intermediate and late maturing types. In general, the stronger the sensitivity to light, the longer the period of vegetative growth is. Thus, the growth period is correspondingly longer. For example, "Nonghu No 6" and "Nongken 58" are late maturing varieties. Conversely, the weaker the sensitivity to light, the shorter the period of vegetative growth is with a correspondingly shorter growth period. Plants with this characteristic belong to early maturing varieties. For example, "Huxuan 19" is such a variety. Varieties of rice having a neutral sensitivity to light and a period of growth in between the two described above are intermediate maturing varieties. For example, "Jianong 15" is such a variety (Table 87).

B. Growth Characteristics of Early Rice

Early rice is the climatic ecological type evolving from late rice which has lost its sensitivity to short daylight conditions. Common early rice varieties all possess a weak basic vegetative growth and a weak sensitivity to light but a strong sensitivity to temperature.

Because early rice possesses a strong sensitivity to temperature the growth period of early rice (mainly the vegetative growth period) is controlled by temperatures (Table 88).

Table 87. Comparison of the Vegetative Growth Periods of Various Late Rice Varieties Under Different Daylight Durations

(a)	(b)	(c)		(d)		(e)		(f)
		(g) (1)	(h) (2)	(g) (3)	(h) (4)	(1)—(4)	(s)	
i)	(j)	69	33	71	19	70	78.6	[illegible]
k)	(j)	68	34	72	20	68	77.3	[illegible]
l)	(m)	61	34	67	20	61	78.2	[illegible]
n)	(o)	74	33	67	23	62	70.3	[illegible]

Note: * Control subject was placed under natural light

KeY:
(a) Var ;ties
(b) Type
(c) Sown on 4/25
(d) Sown on 6/5
(e) Variable vegetative growth period (1) - (4)
(f) Sensitivity to light
(g) Control
(h) 10-hour short daylight
(i) Nongken 58
(j) Late maturing
(k) Nonghu No 6
(l) Jianong 15
(m) Intermediate maturing
(n) Huxuan 19
(o) early maturing
(p) extremely strong
(q) strong
(r) stronger
(s) Shortened (%)

Table 88. Periods of Vegetative Growth of Five Early Rice Varieties Sown at Different Times (Huazhong Agricultural College, 1975)

(a)	(b)							(e)
	3/20 (c)	3/20 (d)	3/30 (d)	4/10 (d)	4/20 (d)	4/30 (d)	7/10 (d)	
(f)	110	60	42	39	34	33	20	(k)
(g)	121	62	47	40	38	32	22	(l)
(h)	126	66	48	45	36	35	23	(l)
(i)	115	61	45	42	38	33	28	(m)
(j)	124	68	50	43	40	39	25	(k)

Key:
(a) Varieties
(b) Period of vegetative growth (days)
(c) Sown on 3/20 Full growth period
(d) Sown
(e) Sensitivity to temperatures
(f) Erjiuqing
(g) Xiangaizao No 8
(h) Huazi No 15
(i) Zhulianzi
(j) Guangluzi No 4
(k) less strong
(l) strong
(m) weak

Since early rice types have either a weak or an extremely weak sensitivity to light, under short daylight conditions, they head only 4 to 11 days earlier than their counterparts. Under an 18 hour long daylight condition, heading is only delayed 3 to 5 days compared to the time of heading under short daylight conditions. Thus in the middle and lower reaches of the Chang Jiang area, early rice sown at the end of March and early April will be able to head rapidly and fruit in June or July when the daylight is relatively long (Examples listed in Table 89).

Table 89. Comparison of the Sensitivities of Varieties of Early Rice (Jiangsu Provincial Agricultural Science Institute, 1973)

品种 (a)	(b) 类型	(c) 从播种到抽穗的天数				备注 (f)
		自然光照 (d)	10小时光照 (e)	13.5小时光照 (e)	18小时光照 (e)	
(h) 二九南2号	特早熟早籼 i	49	45	48	49	播种期 5月21日 (g
(j) 矮南早1号	早熟早籼 k	52	48	49	51	
(l) 二九青	早熟早籼 k	53	48	50	52	
(m) 矮南早39	中熟早籼 n	58	47	51	52	
(o) 广陆矮4号	晚熟早籼 p	69	58	60	62	
(q) 农垦8号	早熟早粳 r	51	46	47	59	

Key:
(a) Varieties
(b) Type
(c) Number of days from sowing to heading
(d) Natural light
(e) __-hour daylight
(f) Remark
(g) Sowing time: May 21
(h) Erjiunan No 2
(i) Especially early maturing early xian
(j) Ainanzao No 1
(k) Early maturing early xian
(l) Erjiuqing
(m) Ainanzao 39
(n) Intermediate early xian
(o) Guangluai No 4
(p) Late maturing early xian
(q) Nongken No 8
(r) Early maturing early geng

It should also be pointed out that early xian and early geng rice have different periods of growth under different temperatures. Studies done by the Jiangsu Provincial Agricultural Science Institute showed that under a definite short daylight period, early xian sown on June 20 (average daytime temperature was 27.[illegible]°C from sowing to heading) had a clearly shorter growth period than early xian sown on May 21 (average daytime temperature was 24.3°C from sowing to heading). The early xian grown under higher temperatures took 2.7 days less from sowing to heading. This explains why the sensitivity to temperature of early xian rice is stronger. Under the above conditions, early geng rice's growth period was prolonged by 1.2 days. This may be

related to the fact that early geng rice's most suitable temperature for growth is between 25°C and 26°C. When the daytime average temperature surpasses 27°C to 28°C, geng rice's development is slower than the speed of growth under normal temperatures of between 23°C and 25°C.

C. Growth Characteristics of Intermediate Rice

Intermediate rice as indicated by its developmental characteristics is a transitional type between early rice and late rice. The developmental characteristics of early and intermediate maturing varieties with a rather short growth period are similar to those of early rice. The late maturing varieties with a longer growth period are similar to late rice varieties in their development characteristics. But studies by the Jiangsu Provincial Agricultural Science Institute indicated that there is a difference between the developmental characteristics of intermediate xian and intermediate geng varieties (Table 90).

Table 90. Comparison of the Developmental Characteristics of Intermediate Xian and Intermediate Geng Rice (Jiangsu Provincial Agricultural Sciences Institute, 1973)

类 型 (a)	供 试 (b) 品种数	营(c)养 生长期 (天)	基本营养 生长期 (天) (d)	可变营养 生长期 (天) (e)	(f) 在可变营养生长期中	
					为较高温度所缩短的天数 (g)	为短日照所缩短的天数 (h)
i) 早熟中籼	6	69.5	46.2	23.3	24.0	− 0.7
j) 中熟中籼	5	96.8	60.6	36.2	20.8	15.4
k) 早熟中粳	4	88.7	49.0	39.7	26.5	13.2
l) 中熟中粳	12	100.9	46.5	54.4	32.4	22.0
m) 迟熟中粳	6	109.8	44.7	65.1	35.5	29.6
n) 晚 粳	6	121.3	44.0	77.3	34.3	43.0

Note: Experiment conducted in Nanjing

Key:
- (a) Type
- (b) Number of varieties tested
- (c) Vegetative growth period days
- (d) Basic vegetative growth period days
- (e) Variable vegetative growth period days
- (f) During the variable vegetative growth period
- (g) Number of days shortened by high temperatures
- (h) Number of days shortened by short daylight
- (i) Early maturing intermediate xian
- (j) Intermediate maturing intermediate xian
- (k) Early maturing intermediate geng
- (l) Intermediate maturing intermediate geng
- (m) Late maturing intermediate geng
- (n) Late geng

Table 90 shows intermediate xian has a relatively strong bas'c vegetative growth while its sensitivity to light and sensitivity to temperature are both weaker than those of the intermediate geng. The sensitivity to light and sensitivity to temperature of intermediate geng is between those of early and late rice.

The fact that intermediate xian's basic vegetative growth is stronger may be related to the high leaf age at which intermediate xian rice becomes sensitive to temperatures. Study of the "Kezi No 6" (IR-8") Central China by the (Huazhong) Agricultural College, Crop Cultivation Teaching and Research Group (1976) showed that that variety begins to become sensitive to light at a leaf age of 7 leaves, requiring over 20 short days (photoperiod of 10 hours) spanning a growth period of four leaves.

Intermediate geng's intermediate and late maturing types are similar to late geng. They have a short basic vegetative growth period of only a little over 40 days. Their sensitivity to light is strong but slightly weaker than late geng. The time of maturity is not delayed for too many days when they are planted under conditions with a 13.5-hour photoperiod and a 10-hour photoperiod. Thus when planted in the middle and lower reaches of the Chang Jiang region they head earlier than late rice. (Table 91)

Table 91. The Number of Days Delayed by a 13.5-hour Photoperiod for Heading of Intermediate Geng Varieties (Jiangsu Provincial Agricultural Sciences Institutes, 1972)

Type	Number of varieties	Number of days delayed by a 13.5-hour photoperiod compared to a 10-hour photoperiod for heading
Early maturing	5	12.6
Intermediate maturing	12	24.8
Late maturing	6	32.8
Late rice	6	39.1

In addition, expe iments conducted by the Jiangsu Provincial Agricultural Science Institute on the photoperiod of intermediate rice varieties showed that early maturing intermediate rice varieties react weakly to photoperiodism. Under an 18-hour long daylight condition, heading was delayed by 5 to 15 days compared to the time of heading under natural daylight conditions. Late maturing varieties manifested a stronger reaction to photoperiodism. Under an 18-hour long day condition, they might not even head (Table 92).

Table 92. Reaction of Intermediate Rice to Short Daylight

品种 (a)	籼粳类型 (b)	熟性 (c)	(d) 从播种到抽穗 (5/21)			
			自然光照 (e)	10小时光照 (f)	13.5小时光照 (f)	18小时光照 (f)
(g) 南京 11	(h) 籼	早 i 熟	75	64	76	89
(j) 科字6号	(h) 籼	晚 k 熟	103	76	93	112
(l) 京引 83	(m) 粳	早 i 熟	70	65	66	75
(n) 农垦 57	(m) 粳	中 o 熟	85	45	70	95
(p) 桂花黄	(m) 粳	晚 k 熟	94	44	83	未抽穗 (q)

Key:
(a) variety
(b) type
(c) maturity
(d) from sowing to heading (t/21)
(e) natural light
(f) __-hour daylight
(g) Nanjing 11
(h) xian
(i) Early maturing
(j) Kezi No 6
(k) Late maturing
(l) Jingyin 83
(m) geng
(n) Nongken 57
(o) Intermediate maturing
(p) Guihuahuang
(q) did not head

III. Application of Growth Characteristics of Paddy Rice Varieties in Production

Chairman Mao taught us: "A very important question regarded in Marxist philosophy is not just to be able to explain the world after having understood the regularity of the objective world but to take the recognition of the objective regularity to actively reform the world." The objective of grasping the sensitivity to temperature, sensitivity to light and basic vegetative growth of paddy rice varieties is to better develop the potential for increasing production of each variety and realize high yields.

A. Application in Cultivation

The application of the developmental characteristics of paddy rice varieties in cultivation first involves reasonable utilization, distribution and combination of early and late rice varieties.

Utilization, distribution and combination of varieties must conscientiously follow the thorough implementation of the policy of "taking grain as the key link in all around development" according to the nation's plans of planting crops and strive towards completion of the mission of production. On the basis of actively improving and creating conditions, using multiple plantings and planting summer-maturing crops well, high and stable yields

of grain must be realized annually by planting more double cropped rice, expanding the intermediate and late maturing varieties of early rice and increasing the area of cultivation for late geng varieties of late season rice. Thus, the following points should be emphasized in the utilization of varieties and their distribution and combination.

First, high yields of single crops and high yields for the entire year should be realized by managing the relationship between single cropping and the entire year well so that efforts towards cropping in the early period can take into consideration croppings in the latter period and each cropping will be for the entire year and this year's efforts will be for next year's gain.

Second, starting out from actual production, reasonable arrangements should be made so that the openings in crop rotation and the combination of varieties according to local circumstances are based on the locality's labor force, (supply) of fertilizers, seasons, water conservancy and mechanization in order that the harvesting, planting and management during the three busy seasons of the year (summer harvest, summer plowing and summer sowing, seizing the proper times to harvest, to plow and to sow, and autumn harvest, autumn plowing and autumn sowing) can be rationally arranged. Especially since timing is tight and the duties are many during the season for "seizing the proper times to harvest, plow and sow." Early rice must be harvested, late season rice must be planted and the cotton crop must be managed well, all of which must be done within half a month's time. The availability of labor is always tight, thus it should be arranged well so that the farming season is not missed.

Third, according to the demands of the livelihood of the masses and national plans, the proportion of nuo rice should be well arranged.

1. Utilization, distribution and combination of early rice varieties

Early rice is the second crop in the triple cropping system. During the growth period of early rice, weather conditions, fertilization and the varieties planted all favor the realization of high yields. The yields also remain rather stable between years. But if the utilization, combination and distribution of the varieties are not reasonable, not only will that year's yield be affected but the timely transplanting of late season rice will also be affected.

Under the present level of production, late maturing varieties should be mainly used as the early rice crop in the double cropping system with an appropriate combination of some early and intermediate maturing varieties. Early maturing varieties should be mainly used as the early rice crop in the triple cropping system while appropriately expanding the intermediate and late maturing varieties.

Early maturing varieties have a short growth period and mature early. These characteristics favor appropriately early planting of late season rice and make it possible to take the initiative in the seasons. But the early maturing varieties presently being used in production are generally strongly

sensitive to temperatures and their need for definite cumulative temperatures from sowing to young panicle differentiation is correspondingly less. If these varieties are sown late, the cumulative temperatures needed for the meristems to change will quickly be reached because of higher temperatures. Thus, the young panicles will differentiate soon after transplating or even while the plant is still in the seed bed. Because the period of vegetative growth visibly shortens, the number of leaves on the main stem is greatly reduced, creating poor nutritive conditions during young panicle differentiation and forming "early panicles" and small panicles." Thus, in the utilization of early maturing varieties, the plants should be sown as early as possible, transplanted as early as possible and plants with a shorter seedling age should be used and overaging of the seedling should be strictly guarded against. Transplanting time should be arranged at the opening of the early crop in the triple cropping system or at the opening of some green manure crop. Smaller row distances should be used to appropriately increase the base number of seedlings.

Since intermediate maturing varieties have a longer growth period than early maturing varieties, their potential for increasing yields is greater than early maturing varieties. To adjust the conflict between the availability of the labor force and the seasons, appropriate inclusion of some intermediate maturing varieties is necessary.

Late maturing varieties have a long growth period and the potential for increasing yield of the varieties is great. In recent years, practice has proven that expanding the planting areas of late maturing varieties is a way to increase the yield of early rice. A survey conducted by the Jiangsu Wuxian Bureau of Agriculture in 1975 showed that the level of production increased as the proportion of late maturing varieties expanded (See Table 93).

Table 93. Performance of Different Types of Early Rice Varieties in Yield of Each Cropping (jin)

Varieties / Croppings	Early maturing	Intermediate maturing	Late maturing
Double cropping	785.9	845.9	945.9
Early triple cropping	-	1054.9	1141.1
Late triple cropping	723.2	770.7	933.2

In expanding late maturing varieties, the plants should be sown early so as not to affect the timely transplanting of late season rice. The following steps can be taken in this regard.

First is popularization of the method of cultivating seedlings under thin plastic sheets. Cultivation of seedlings under thin plastic sheets makes early sowing possible, enables seedlings to grow to a sufficient age and makes maturing earlier possible. In the middle and lower reaches of the Chang Jiang region, the sowing period of early rice generally begins only during the first ten days of April. When thin plastic sheets are used to cultivate seedlings, late maturing varieties following green manure crop can be sown around March 20, transplanted during the first ten days in May and mature at the end of July. Late maturing varieties of triple crops cultivated under thin plastic sheets can be sown at the end of March or early April, transplanted during the middle ten days of May and mature at the beginning of August.

Second is popularization of two stage seedling cultivation. Two stage cultivation of seedlings enables earlier sowing, appropriate lengthening of the seedling age and enables maturity to occur 2 to 3 days earlier. In general, seeds sown in the middle ten days of April will have grown enough for first transplanting in the middle ten days of May and a second transplanting in the middle ten days of June and mature about August 10.

Third is the practice of sparse sowing and allowing the seedlings to reach a sufficient age for the cultivation of strong seedlings. Appropriate early and sparse sowing and extending the seedling age several days will similarly enable plants to mature early and yield large panicles. When these practices are grasped concretely, then at the early triple crop opening in which there is extra time for seedlings to age and under sparse sowing conditions, the seedlings can be sown so that the seedling age is held within 45 days. For the late triple crop opening, the seedling age should be held within 40 days and over aging should be strictly guarded against.

2. Utilization, distribution and combination of late season rice varieties

Late season rice is the last crop of the entire year. It is often the one crop that most sharply reveals the problems in crop distribution. If the distribution of early rice for summer maturing crop is appropriate, the arrangement of the late season rice varieties will be appropriate. If one of the crops of the two previous crops that season are not distributed reasonably, time allowed for repeat planting of late season rice will be less, the seasons will be tight and production will not be high. If the late season rice is not distributed properly itself, reasonable distribution of the entire year's crops will be affected.

In the middle and lower reaches of the Chang Jiang region, the yield of late season rice has over the past years been [illegible] and unstable, especially since the growth period is easily affected by cold air which affects safe

full heading and maturity of late season rice. Also, the vegetative growth period in the large field of late season rice is short and the conflict of seasons is more pronounced than that of the two previous crops (summer maturing crop and early rice) that year. In addition, the distribution of late season rice varieties involves reserving areas for specialized seedbeds for late season rice as well as assurances that the late season rice will achieve full heading before the period of full heading. Thus, it is important to look forward and consider that which has gone before in order to reasonably arrange the ratios of the various varieties and assure late season rice's overall increase in production. At present, late geng varieties are generally the dominant varieties planted as late season rice along with a combination of some intermediate geng, intermediate nuo and early xian varieties.

Late geng varieties are used as the dominant variety as late season rice in the middle and lower reaches of the Chang Jiang because of its high yields and superior quality. Its use is also related to the facts that late geng has a relatively short vegetative growth period, its sensitivity to light begins at a young leaf age and within a definite period and different sowing and transplanting times do not affect full heading very much. But, because late geng varieties possess strong sensitivities to light and temperatures and their growth period is long, the time for growth in the large field is tight. Thus, to assure that late geng varieties will head fully and safely (The safe full heading time in the Shanghai area is September 25), the insufficient growth period should be made up while in the seedbed to assure that late geng will grow to a sufficient seedling age. Any sufficient aging of the seedling should be strictly prevented.

Intermediate geng and intermediate nuo can be used as late season rice because their developmental characteristics are similar to those of late geng. But, their sensitivites to light and temperature are weaker than those of late geng. Thus, a certain delay in sowing and transplanting times will not affect the full heading time too much. Also because their growth period is rather short, they are not affected by low temperatures during the latter period as greatly as late geng. Therefore in production, intermediate geng and intermediate nuo are varieteis mostly used as the closing crop of late season rice.

When cultivating early xian as late season rice, the characteristics of early xian being strongly sensitive to temperatures and intolerent to low temperatures must be taken into consideration (During the fruiting period of xian rice varieties the average daytime temperature must not be lower than 23°C to 25°C. Thus in the Shanhai area, the safe full heading period should occur earlier or between September 10 and 15, and the beginning period of young panicle differentiation should also occur earlier, between August 10 and 15). Suitable varieties should be selected on the basis of the region's safe full heading period, the growth period of the varieties and their characteristics of sensitivity to light and temperatures, thus assuring an appropriate sowing time and seedling age. A seedling age of 15 days is appropriate for early

and intermediate maturing varieties with a strong sensitivity to temperature. This will enable an early opening between crops and is less risky but the yield is ordinary. The use of intermediate and late maturing varieties with strong sensitivity to temperature results in higher yields but the plants must be transplanted early. Using early and intermediate maturing varieties with a weaker sensitivity to temperature offers a great potential for increasing yield and seems to be more ideal, for instance the "Zhulianai" variety is such a variety. When cultivating early rice as late season rice, the only requirement is to manage the crop well. The yield will not be low. For example, the 82nd Brigade of the Jinwei Commune of Jinshan County, Shanghai City, a high yield unit, planted "Guangluai No 4" as a late season rice and produced around 1,000 jin per mu. The main reason was due to existence of favorable temperature and light conditions at the time of the reproductive growth period when the temperatures lowered and the duration of daylight shortened. There were plenty of sunny days and except for a slight shortening of the vegetative growth period, the reproductive growth period (especially the filling and fruiting periods) was variably prolonged. Therefore, the yield correspondingly rose. Thus, in some regions, late season rice can be combined with a definite proportion of early rice varieties to benefit development of double season rice. In triple cropping regions this combination can also provide an earlier opening for the late crop and assure an increased yield for the entire year.

Intermediate xian rice varieties such as "Kezi No 6" have a strong basic vegetative growth and [only] become sensitive to light at a high leaf age. Their reaction to short daylight photoperiods emerges late and they need more photocycles to induce further growth. Thus when the plants become sensitive to light, the temperatures have already begun to drop. In addition, these varieties are not tolerant of cold and easily fail to head fully or although full heading is achieved, filling, fruiting and maturation cannot be completed normally. Thus, these types of varieties are not suitable as late season rice.

The actual arrangement of the crop opening for late season rice in the Shanghai region, in general, follows the following principles:

(1) Opening for the early rice crop of the double crop and for some of the early rice crops of the triple crop maturing before the end of July: These openings are in the early seasons when the weather conditions are better. Thus, the openings are suitable for planting late-maturing late geng varieties which have long periods of growth. The varieties' potential for increasing yield can be fully developed to achieve high yields.

(2) Opening for the early rice crop of the triple crop maturing at the beginning of August: The season of this opening is in between and the conditions for growth are good. Generally this opening is used to plant intermediate-maturing late geng varieties with an appropriate combination of a definite proportion of early xian and intermediate geng or intermediate nuo varieties. Late geng varieties have a strong sensitivity to light and can

be cultivated into healthy seedlings by sparse sowing and prolonging the seedling age to supplement the insufficiency of the vegetative growth period in the large field.

(3) Opening for the early rice crop in the triple crop maturing before August 7: The seasons are tight at this time and the growth period in the large fields visibly shortens. In general, only intermediate rice varieties with a short growth period or early-maturing late geng varieties that are more tolerant to low temperatures are planted. To achieve high yields and assure safe full heading of late season rice, late-maturing late geng varieties such as "Nonghu No 6" can be cultivated in two stages to solve the conflict between high yield and safe full heading.

In production practices, the poor and lower-middle peasants describe vividly the combination and distribution of late season rice varieties in four sentences: "Late geng types are launched as the first blast, early xian and intermediate rice (intermediate geng and intermediate nuo) serve as bridges, early-maturing late geng follow in pursuit and late geng "Nonghu" tosses the dragon's tail."

Distribution and combination of varieties at various areas depend upon the actual conditions of the locality. Thus, arrangement should be made according to local circumstances and no set pattern should be followed. The distribution and combination of varieties in Wuxian, Jiangsu Province, is illustrated diagrammatically in Diagram 69 as reference.

B. Estimating the Growth Period

After expansion of the triple cropping system in the middle and lower middle reaches of the Chang Jiang regions, the openings in crop rotation have become tight and the farming activities have become concentrated. It is therefore extremely important and significant in paddy rice production to predict the growth period of paddy rice and especially to predict the maturation period of early rice and the full heading period of late season rice.

1. Predicting the maturation period of early rice

Since early rice is strongly sensitive to temperatures, its period of growth is controlled by the effective cumulative temperature to a large degree. In the Shanghai area, we can guesstimate the maturation period of a variety by observing the difference in cumulative temperatures and by subtracting the effective cumulative temperature between that year's sowing date of early rice and June 10th from the effective cumulative temperature of the entire growth period of the variety and using this difference to check against the effective cumulative temperature table for normal years between June 11 and the time of maturity.

For example, "Ainanzao No 1" sown on April 28, will have a cumulative temperature of 446 (degree-days) on June 10 according to data of the local weather station or actual observation. Table 94 shows that the effective cumulative temperature for the entire growth period of "Ainanzao No 1" in

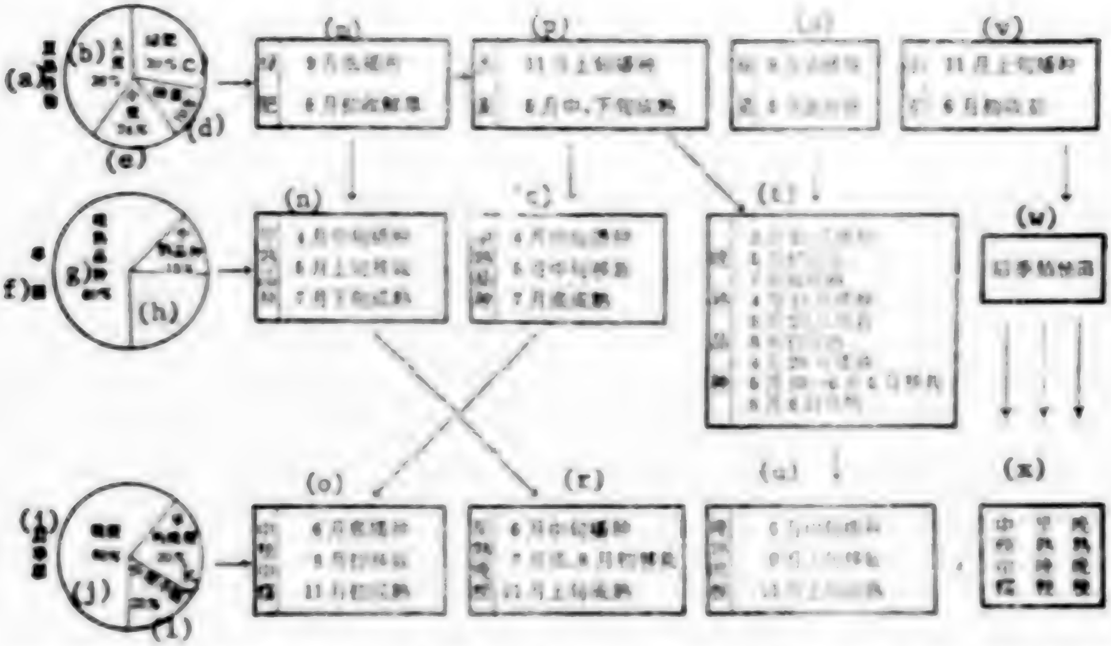

Diagram 69. Crop Distribution and Combination of Varieties in the Triple Cropping System of Wuxian, Jiangsu Province

Key:
(a) Summer maturing crop
(b) Barley 36%
(c) Green Manure 30%
(d) Rape 10%
(e) Wheat 24%
(f) Early rice
(g) Late-maturing varieties 60%
(h) Intermediate-maturing varieties 15%
(i) Late season rice
(j) Late geng 60%
(k) Early-maturing late geng 20%
(l) Intermediate-maturing intermediate nuo 20%
(m) Green manure — Sown at end of September; Harvest of fresh grass at the beginning of May
(n) Early maturing — Sown in the middle ten days of April; Transplanted in the first ten days of May; Maturing in the last ten days of July
(o) Intermediate geng, Intermediate nuo — Sown at the end of June; Transplanted at the beginning of August; Maturing at the beginning of November
(p) Barley — Sown in the first ten days of November; Maturing in the middle of last ten days of May
(q) Intermediate-maturing varieties — Sown in the middle ten days of April; Transplanted in the middle ten days of May; Maturing at the end of July

[To be continued on following page]

Key: [continued]

(r) Early-maturing late geng — Sown in the middle ten days of June
Transplanted at the end of July and early August
Maturing in the first ten days of November

(s) Rape — Sown at the end of September
Harvested at the end of May

(t) Late-maturing varieties — Sown on March 25
Transplanted at the beginning of May
Maturing at the end of July
Sown on April 15
Transplanted on May 20
Maturing at the beginning of August
Sown on April 25
Transplanted between May 25 and June 5
Maturing on August 6.

(u) Late-maturing late geng — Sown in the middle ten days of June
Transplanted in the first ten days of August
Maturing in the first ten days of November

(v) Wheat — Sown in the first ten days of November
Harvested at the beginning of June

(w) Late season rice seed bed

(x) Intermediate geng intermediate nuo
Early-maturing late geng
Late-maturing late geng

a normal year is 1275 (degree days). The effective cumulative temperature required by "Ainanzao No 1" from June 11 to maturity is 829 (degree days). Table 95 shows that the cumulative temperature on August 2 is 834 (degree-days) which is close to the required cumulative temperature, thus the maturity date for "Ainanzao No 1" will be on August 2.

The above shows that to predict the maturity time of early xian rice, tables similar to table 94 and 95 must be complied for the locality. These tables are different for different regions and different varieties. Other localities that use this method must make predictions according to the situation at their own localities.

2. Predicting the full heading period of late season rice

Late season rice varieties presently cultivated are predominantly late geng varieties. Since late geng varieties have strong sensitivities to both temperature and light, prediction of their growth periods is much more complicated than predicting varieties that are simply sensitive to temperatures. Here, the effects of duration of light must be considered as well as the effect of temperature and the mutual effects of light and temperature. Since the full heading period of late season rice involves the question of safe

Table 94. Effective Cumulative Temperatures of the Entire Growth Period of Different Early Xian Varieties

Varieties	Type	Growth period in ordinary years	Effective cumulative temperatures in ordinary years (degree days)
Erjiulu No 1	Extremely early-maturing early xian	90	1162.5
Ainanzao No 1	Early-maturing early xian	95	1275.0
Erjiuqing	Early-maturing early xian	96	1286.0
Zhulianai	Early-maturing early xian	97	1303.5
Erjiunan No 1	Early-maturing early xian	98	1316.0
Ainanzao No 39	Intermediate-maturing early xian	100	1352.3
Guangluai No 4	Late-maturing early xian	117	1444

Note: (1) The above table was compiled from data spanning 4 years between 1971 and 1974 provided by the Shanghai Municipality, Shanghai County Superior Variety Farm, Shanghai County Yutang Brigade and Chuansha County Superior Variety Farm.

(2) Ordinary year's effective cumulative temperature is calculated from above 10°C.

Table 95. Effective Cumulative Temperatures Above 10°C from June 11 to the Following Dates in the Shanghai Area (Ordinary Average Values)

(a) 日 期 (月/日)	7/23	7/24	7/25	7/26	7/27	7/28	7/29	7/30
(b) 有 效 积 温	653	677	688	706	725	743	761	779
(a) 日 期 (月/日)	7/31	8/1	8/2	8/3	8/4	8/5	8/6	8/7
(b) 有 效 积 温	798	816	834	852	870	888	906	924
(a) 日 期 (月/日)	8/8	8/9	8/10	8/11	8/12	8/13	8/14	8/15
(b) 有 效 积 温	943	960	978	996	1014	1032	1050	1067

Key: (a) Date (month/day)
(b) Effective cumulative temperature

heading, the method of prediction using temperature and light coefficients developed by the Jiangsu Nanjing Agricultural Science Institute (1975) has a certain value as a reference although as yet no method has been devised based upon a sound theoretical foundation for the prediction of late season rice's full heading period. Through research the Jiangsu Nanjing Agricultural Science Institute developed a formula for temperature and light during the growth period of varieties sensitive to light. It is a multiple regressive function:

$$y = a + b_1 x_1 + b_2 x_2 + b_3 x_3$$

where y is the number of days between sowing and full heading of the variety for which a prediction is made;

a is the theoretical number of days or standard days under 30°C between sowing and full heading when the seed is sown on June 21.

x_1 is the difference between the average daytime temperature (t°) from sowing to heading and 30°C, i.e.,

$\overrightarrow{x_1}$ = 30°C - t°C, or the temperature deviation.

x_2 is the difference between the actual sowing time and June 21, expressed as 0 when the actual sowing time is on June 21, negative when sown after June 21 and positive when sown before June 21, also called the sowing time deviation.

b_1 is the number of additional days between a fixed sowing time and full heading time for every drop of 1°C in the daytime average temperature from sowing to heading, also called the coefficient of temperature sensitivity.

b_2 is the number of additional days between sowing and full heading for each day the seeds are sown earlier under fixed temperature, also called the coefficient of light sensitivity.

b_3 is the corrective coefficient of seedling age, that is, the number of additional days between sowing and full heading for each additional day the seedling age over 30 days. Thus taking a seedling age of 30 days as standard, late geng has a corrective coefficient of 0.1, early maturing late geng has a corrective coefficient of 0.2 and intermediate geng has a corrective coefficient of 0.25.

x_3 is the number of days over the 30-day seedling age.

In the formula, a b_1 and b_2 must be actually measured at the particular locality over 10 or more areas before the formula can be used.

Data of the Jiangsu Nanjing Agricultural Science Institute over many years provide information for the following formulas for the prediction of the number of days between sowing and heading for some intermediate and late geng varieties in Nanjing at 32° latitude N:

Nonken No 58": $y = 96.5 + 0.82\ x_2 + 0.1\ x_3$

"Nonghu No 6": $y = 93.5 + 0.82\ x_2 + 0.1\ x_3$

"Shuangfeng No 1": $y = 81.7 + 2.6\ x_1 + 0.51\ x_2 + 0.2\ x_3$

"Huxuan No 19": $y = 78.7 + 2.6\ x_1 + 0.51\ x_2 + 0.2\ x_3$

"Nangeng 33": $y = 71.1 + 3.0\ x_1 + 0.35\ x_2 + 0.25\ x_3$

For example, "Huxuan No 19" sown on June 18, with a seedling age of 45 days and under a normal annual average temperature of 26.5°C between June 18 and September 22, requires:

$y = 78.7 + 2.6 \times (30-26.5) \pm .51 \times (22-18) + 0.2 \times (45-30) = 92.64$ days, i.e., 93 days after sowing to head fully or on September 19.

Studies indicate the above formula derived from experience can be applied to other varieties of the same type after correcting for the "standard number of days." In actual application, it is more reliable to use data of the locality and of the actual fields.

C. Application in Introducing Varieties

When introducing varieties from other areas, one must first take into consideration the varieties' sensitivity to temperature, sensitivity to light and basic vegetative growth characteristics. When introducing varieties with a strong sensitivity to temperatures, the effective cumulative temperatures within the growth season of paddy rice of the locality should be considered to see if the effective cumulative temperatures are enough to satisfy the need of the varieties being introduced. When introducing varieties with a strong sensitvity to light, the duration of daylight of a period within the growth season of paddy rice of the locality should be considered to see if the duration of daylight of that period is enough to satisfy the need of the varieties being introduced. When introducing varieties with a strong basic vegetative growth, conditions during the growth season of paddy rice of the locality should be considered to see if the conditions for basic vegetative growth can be assured.

Introducing varieties to different latitudes: Since northern varieties have a strong sensitivity to temperature and a weak sensitivity to light, their growth period will generally shorten when introduced to the south. In particular, early geng grown in regions north of Changchun requires a low effective cumulative temperature during the entire growth period and is sensitive

to temperatures. When introduced to the south, it should be sown early and the seedling age should not be too high. Only by properly prolonging the growth period can it achieve high yields. In 1956, the early geng "Qingsen No 5" variety was introduced into some provinces of the Chang Jiang Valley. Because the variety's strong sensitivity to temperatures was not understood, the early rice crop yield was reduced. Early rice varieties of the south are strongly sensitive to temperatures and have a weak sensitivity to light. When southern varieties are introduced to the north, the growth period should be appropriately prolonged to enhance the chances of success. Late rice varieties are strongly sensitive to light and temperatures. It is more difficult to introduce late rice varieties of the south to the north because they often cannot head or heading is delayed, thus causing a reduction in yield. Some early and intermediate rice varieties, especially intermediate xian varieties, have a strong basic vegetative growth. The growth period of these varieties is also affected by temperature and conditions of light. When introducing these varieties of the south to the north, their growth periods will also visibly be prolonged. For example, the entire growth period of "Kezi No 6" grown in the Philippines lasts between 110 and 125 days but when grown in Yangzhou, the growth period lasts over 160 days. This should also be taken into consideration.

Introducing varieties from different elevations above sea level at similar latitudes: The growth period shortens when a variety is introduced from a high elevation to a lower elevation. For example, at 30°C N latitude in Lichuan County of Hubei Province (at 1070 meters above seal level), the native tall stem xian rice "Zhimagu" required 125 days to grow from the time of sowing to full heading. When it was introduced to the plains of Wuhan at a similar latitude, only 95 days were needed for it to grow from sowing time to full heading. The growth period visibly shortened. When introducing a variety from a lower elevation to a higher elevation, the growth is prolonged. For example, "Nongken 58" cultivated in plains of the middle and lower reaches of the Chiang Jiang (at 30°C latitude N) extended its growth period by 30 days after it was introduced to Linchuan County.

Introducing varieties to and from regions at similar elevations above sea level and at similar latitudes can be done more successfully because the temperatures and daylight conditions are similar.

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CHAPTER 7. PHYSIOLOGICAL BASIS FOR REASONABLY DENSE PLANTING

The basic principles of reasonably dense planting lies in the effective utilization of light energy and full utilization of land to assure the normal growth of the individual plant and the greatest development of the colony so that the number of panicles, the number of grains and the weight of grains in a unit area can be unified to realize a high yield. Since the yield of paddy rice in based on the colony, a reasonable structure of the colony must be established to produce a larger photosynthetic organ (leaf surface area) for the production of more photosynthetic products so that high yields can be realized. However, since the colony is founded upon the basis of normal growth and development of the individual plant, the structure of the photosynthetic organs and function of the individual plant must be understood so that the dialectic relationship between the colony and the individual in the formation of the yield as well as the utilization of light energy by the colony can be discussed in order to provide a theoretical basis for reasonably dense planting.

I. The Organs and Process of Photosynthesis

Physiologically, two conditions must exist for paddy rice to produce high yields: There must be a larger photosynthetic organ (the leaves) and there must be more photosynthetic products. Thus, we must first gain a simple and clear understanding of the photosynthetic organ--leaves and the process of photosynthesis.

A. Shape and Structure of the Leaf

The paddy rice leaf is the major organ for photosynthesis and the manufacturing of nutrients. The ability of the leaf to perform photosynthesis is related to its structure and shape. The paddy rice leaf consists of the leaf blade, the leaf sheath, leaf pillow, the auricle and the ligule. They are introduced below:

1. The Leaf Blade

The leaf blade is flat and extends into space to facilitate the receipt of sunlight, absorption of carbon dioxide and performance of photosynthesis. The structure of the leaf blade mainly includes the epidermis, the parenchyma, the mechanical tissue and the large and small vascular bundles (Diagrams

70, 71). The upper and lower epidermis each has a layer of cuticular cells which are the protective tissues of the leaf. The cuticular cells are rectangular in shape and generally have silicified with a heavy sediment of silicic acid to protect the inner tissues and reduce loss of moisture. The rim of the leaf is undulated with many small protuberances or tumor-like protuberances. The outer walls of some of the extremely small cuticular cells has acicular down. Many aerate pores (stomates) are on the epidermis through which air passes in and out (Diagram 72). They are arranged in an orderly fashion. In general, there are more stomates on the upper leaves of the plant, more on the upper part of the single leaf and more on the front side (upper side) of the leaf than on the back. Spongy cells consist of several especially large parenchyma cells between the vascular bundles. When the moisture in the leaves is reduced, the spongy cells shrink because of reduced pressure causing the leaf surface to curl up and shrink and thereby, reducing the surface of evaporation. Thus, the spongy cells are also called the mechanical cells. There are spongy cells on the front and the back of the leaf but those on the front side are arranged in order.

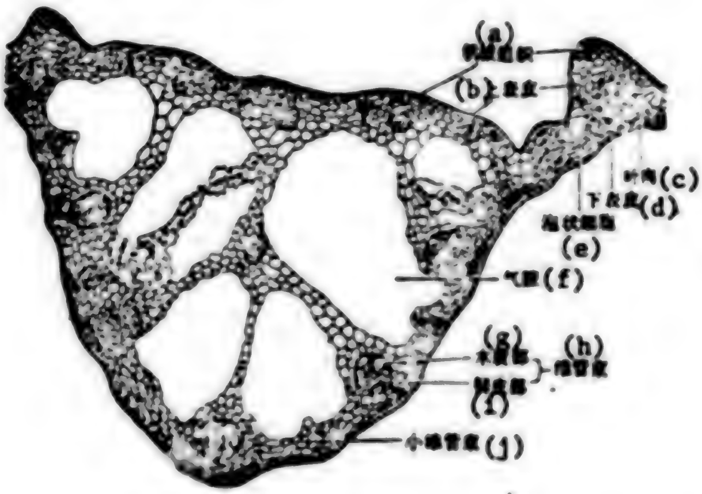


Diagram 70. Cross Section of the Paddy Rice Leaf at Midrib Vein

Key: (a) mechanical tissue
(b) upper epidermis
(c) mesophyll
(d) lower epidermis
(e) spongy cells
(f) air cavity
(g) xylem
(h) vascular bundles
(i) phloem
(j) microvascular bundles

Underneath the epidermis is a layer of the parenchyma tissue with vascular bundles running through it as parallel veins. The vascular bundles in the mesophyll are not uniform in size and the mechanical tissue's degree of development varies according to the difference in size of the vascular bundles.

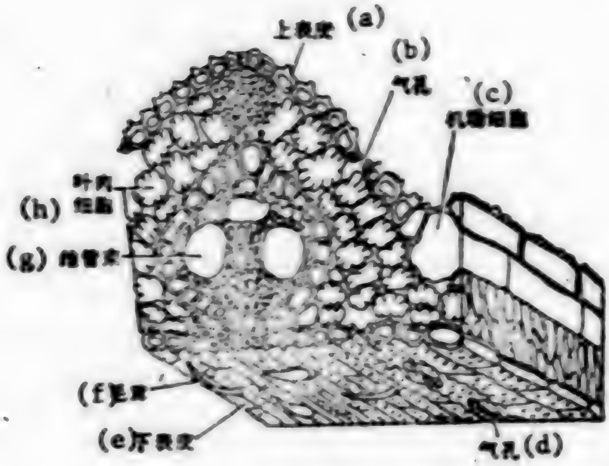


Diagram 71. Inner Structure of the Paddy Rice Leaf (Hoshigawa Kiyoshin) 1975)

Key: (a) Upper epidermis
(b) stomates
(c) mechanical cells
(d) stomates
(e) lower epidermis
(f) pubescence
(g) vascular bundle
(h) mesophyll cell

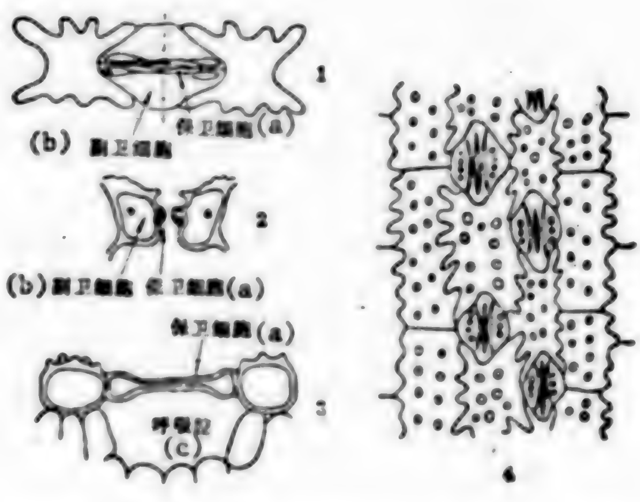


Diagram 72. Structure of the Stomates of Paddy Rice
1. Surface view 2. Horizontal cross section along (1)
3. Vertical cross section of (1) 4. Distribution of stomates on back of leaf

Key: (a) guard cell 1
(b) secondary guard cell 2
(c) respiratory cavity

The mesophyll is composed of parenchyma cells of the same shape lined up in columns. These are the places where the chloroplasts that perform photosynthesis are distributed. The horizontal cross section of the leaf shows the mesophyll is between the upper and lower epidermis. The mesophyll cells near the epidermis are lined up orderly, facilitating photosynthesis. [These are also called palisade parenchymacells.] The mesophyll cells at the center are irregular and have larger spaces in between to facilitate the dispersion of carbon dioxide. [These are called spongy parenchyma cells.]

The mesophyll cells contain large amounts of chloroplasts in the shape of circular discs distributed in the cytoplasm. Chloroplasts move about with the cytoplasm. When the light is weak, the chloroplasts distribute themselves in the cytoplasm and fully utilize scattered light. When the light is strong, the chloroplasts line up along the cell walls reducing the surface area receiving light to avoid damage by strong light. Chloroplast is composed of three parts. The outermost surface has two layers of thin membranes. The inside is the colorless plastid and the grana which contain pigments. The plastid is mainly composed of protein and large amounts of enzymes related to the assimilation of carbon. The grana consist of quantosomes and thylakoids stacked up. The grana are distributed in the plastid. Each cloroplast contains many grana. Chlorophyll molecules line themselves on the thylakoids thus facilitating photosynthesis. Chlorophyll absorbs light energy to manufacture organic substances.

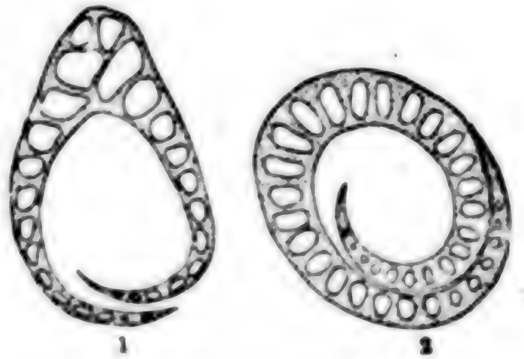
Chlorophyll is green. Its darkness or lightness and its growth is determined by the genetic characteristics of the variety of the variety of paddy rice. The chlorophyll changes as the physiological condition of the paddy rice plant and cultivation and management conditions change. Chlorophyll is in constant formation and decomposition within the chloroplast. Where fertilization, irrigation and light conditions are good, more chlorophyll is formed than decomposed, its color is dark green and it facilitates photosynthesis. Where fertilization and irrigation are insufficient and the light condition is poor, the destruction of chlorophyll is hastened, allowing the emergence of other pigments of the chloroplast such as yellow (carotenoids, xanthophylls) which are not beneficial to photosynthesis. The darkness or lightless of the color of the leaf also reflects the relationship between the carbon-nitrogen metabolism in the plant body and vegetative and reproductive growth. In production, the color changes of the leaves are often taken as important indicators for diagnosis of the condition of the seedlings and for fertilization and irrigation.

The veins consist mainly of vascular bundles and the mechanical tissue. The vascular bundles perform the function of transportation. The xylem and the phloem transport moisture and nutrients respectively. The vascular bundles in the leaves, the stems and roots are connected forming a unified system.

2. The Leaf Sheath

The leaf sheath envelops the stem. It is thick in the center and thin on the two sides which fold up but are not connected. The leaf sheath is generally green. The leaf sheath consists of the epidermis, the parenchyma, vascular bundles and the mechanical tissues. The horizontal cross section of the leaf sheath shows the outer epidermis is formed by rectangular epidermal cells. Stomates are distributed among the veins of the leaf. The stomates connect with the air cavities in the parenchyma cell tissue. These are the main channels through which oxygen is transported from the parts of the plant above ground to the root system. The parenchyma of the leaf sheath stores starch. The horizontal cross section of the leaf sheath varies according to different leaf positions. During tillering, the leaves growing on the nodes of the tillers have leaf sheaths that are triangular. After jointing, the leaves on the elongated nodes have leaf sheaths that are circular without a pronounced sheath ridge (Diagram 73). The latter type of leaf sheath has a greater ability to store starch. Since its shape and its function have both changed, this type of leaf sheath is generally called a deformed leaf sheath.

The base of the leaf sheath that surrounds the protuberance at the node of the stem is called the leaf node. The tissues in this part of the leaf sheath are tighter in structure than the tissues in the other parts of the leaf sheath and have smaller air cavities. Their mechanical tissue is developed and the degree of cuticular formation is extremely pronounced, thus the mechanical strength of the leaf node is strong and the tissues are strongly elastic. When the plant lodges, the cells of the bottom side of the leaf node visibly elongate and wrinkle up to straighten the plant. After this bending is completed, the original cuticular cell wall thickens to strengthen the bend.



1 2

Diagram 73. Cross Sections of Two Different Leaf Sheaths

1. Horizontal cross section of leaf sheath enfolding the stem during tillering.
2. Horizontal cross section of leaf sheath of the first internode above ground enfolding the stem

3. The Leaf Pillow, the Ligule and the Auricle

The divider of the leaf sheath and the leaf blade is called the leaf pillow. Inside the leaf pillow is the tongue-shaped protuberance extending from the tip of the leaf sheath like a thin plate called the ligule. The ligule of a leaf that has ceased to grow is a dead tissue but functions mainly to close the gap between the stem and the leaf sheath and protect the young and tender parts of the stem from losing moisture. It is a rain guard preventing rain from flowing into the gap between the leaf sheath and the stem. On both sides of the leaf pillow at the base of the leaf are small hook-shaped blades called auricles.

B. Growth of the Leaf

The incomplete leaf and the first and second complete leaf of paddy rice are differentiated in the mature seed. The other leaves differentiate, emerge and grow from the meristems only after the seed has germinated.

The first to the third complete leaves on the main stem emerge and grow during the young seedling period. The last three leaves emerge and grow during the young panicle differentiation period. The rest of the leaves all emerge and grow during tillering. The numbers of leaves on the main stem vary according to variety. Early rice has about 11 to 13 leaves, intermediate rice between 14 and 15 leaves and late rice about 16 to 18 leaves. Naming of the paddy rice leaves and the leafing process are illustrated in Diagram 74 (Tanaka, 1961).

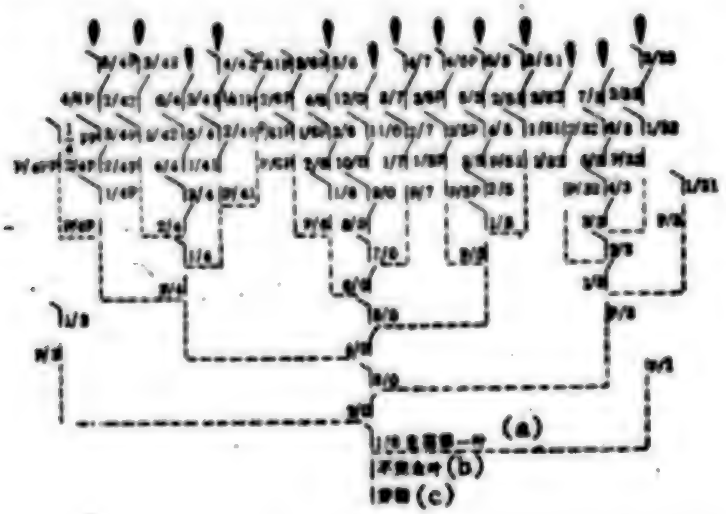


Diagram 74. Naming of the Paddy Rice Leaves and the Leafing Process

Key: (a) first leaf of main stem
(b) incomplete leaf
(c) plumule sheath

The growth process of a leaf of the paddy rice plant can be represented in general by an "S" curve, i.e., the dry weight increases gradually at first and reaches a peak and then reduces and finally stabilizes.

The growth of paddy rice leaves can be considered as a chain reaction. The emergence and growth of 1/0 is necessary to the growth of 2/0 and the growth of 3/0 depends upon 2/0 and 1/0. In general, the formation of n/0 is assisted by n-1/0, n-2/0 and n-x/0 and beneficial to the growth of n + 1/0, n + 2/0 and up to n + x/0. (x indicates leaves that emerge later).

Studies and analysis by Tanaka (1956) showed that the function of each leaf during the growth process of paddy rice is different (Diagram 75). Understanding the different functions helps us take corresponding measures to stimulate or suppress the growth of leaves to achieve surplus yields.

During a certain period in the growth of paddy rice, the leaf that reaches the highest dry weight and performs the greatest physiological function is called the "activity center leaf." The activity center (leaf) is especially significant to the growth and development of the plant. The main characteristic of the activity center is its highest photosynthetic strength (Table 96) and its extreme sensitivity to external environment.

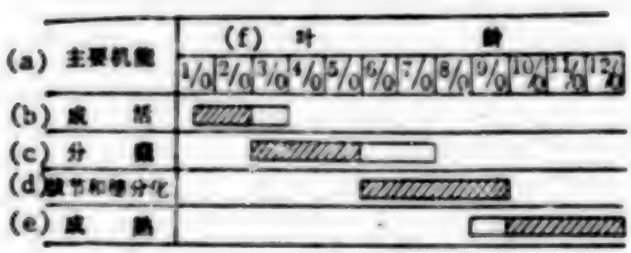


Diagram 75. Major Function of the Leaves on the Main Stem of Paddy Rice

Key: (a) major function (d) jointing and panicle differentiation
(b) emerging and living (e) maturation
(c) tillering (f) leaf age

The number of days between the emergence of two neighboring leaves is called the leafing cycle. The leafing cycle of the first three leaves to emerge is short, generally about 3 days. Leaves that emerge during tillering have a longer leafing cycle, generally between 5 and 6 days. Leaves emerging after jointing have a visibly prolonged leafing cycle, generally between 7 and 9 days.

During the life of the paddy rice, there are two turning points in the leafing cycles which are indicators of the changes in the growth stages of paddy rice. The first turning point is the weaning stage indicating the

plant has changed from the heterotrophic stage to the autotrophic stage. The second turning point is the jointing period indicating the plant has changed from the vegetative growth stage to the reproductive growth stage.

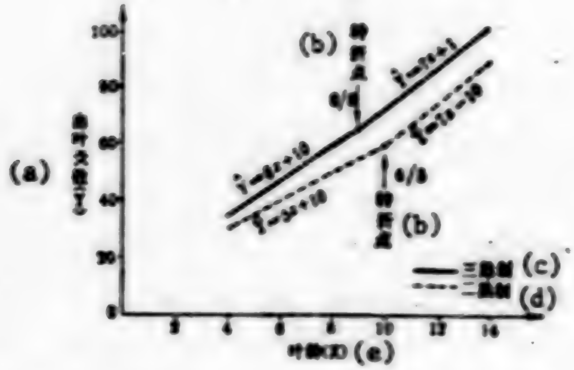
Observations by the Zhejiang Jiaxing Prefectural Agricultural Science Institute (1975) indicate the turning point of the leafing cycle of early rice "Guangluai No 4" is between the leaf ages of 8 leaves and 9 leaves (Diagram 76). As a triple crop, the timing of the turning point is too early and as a double crop it is too late. Under normal fertilization, irrigation and management conditions, the leafing cycles during each growth stage is symmetrically stable but will change because of environmental conditions. A lack of fertilization is indicated if during the vegetative growth period fertilization and irrigation are insufficient and the leafing speed slows. After the plant has begun its reproductive growth period, overfertilization during the latter period will prolong the leafing time and the plant will manifest overly extensive growth and remain green. Thus the leafing cycle can also be used as an indicator in the diagnosis of the normality of the growth of paddy rice.

Table 96. Activity Center Leaf and Strength of Photosynthesis of Each Leaf on the Main Stem of Paddy Rice (Tanaka, 1961)

Date of Inspection	Leaf	Absorption of carbon dioxide (milligram/100 centimeter^2/hrs
June 28	7/0	13.0
	6/0	36.6
	5/0	58.7*
	4/0	15.0
July 27	10/0	18.3
	9/0	26.6*
	8/0	20.3
	7/0	14.1
September 4	12/0	11.1*
	11/0	6.1

* Activity center leaf

The difference between the lengths of leaves of different varieties is great. External conditions have a definite effect upon the length of the leaves. The general pattern is that the length of the leaves progresses from short to long from the first leaf upward and then shortens from the reverse second leaf to the reverse fourth leaf. The lengths of leaves of three intermediate paddy rice varieties measured in 1972 by the Jiangsu Agricultural Academy are shown in Diagram 77.



Diag·am 76. Comparison of the Leafing Time and Turning Point in Leafing of the Leaves of the Main Stem of "Guangluai No 4" in Triple Cropping and Double Cropping.

Note: In the diagram, $\hat{y} = 6x + 10$ is the isopleth regressive function. $\hat{y}$ represents experience formula.

Key:
(a) number of days of leaving (Y)
(b) turning point
(c) triple cropping
(d) double cropping
(e) leaf age (X)

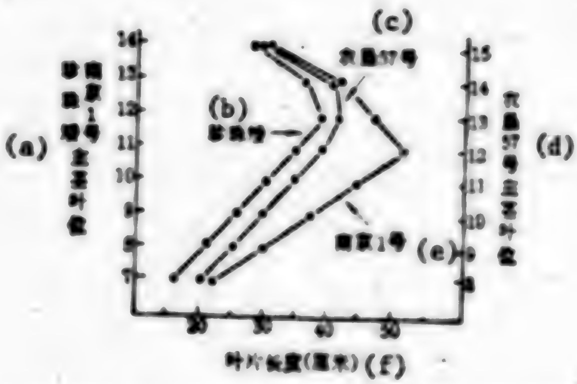


Diagram 77. Lengths of Leaves of Three Intermediate Rice Varieties

Key:
(a) leaf position on main stem of Zhenzhuai and Nanjing No 1
(b) Nongken No 57
(c) Zhenzhuai
(d) leaf position on main stem of Nongken No 57
(e) Nanjing No 1
(f) Leaf length (cm)

Diagram 77 shows that "Zhenzhuai" and "Nongken No 57" varieties' reverse third leaf is the longest, the length of the reverse second, reverse fourth and reverse third leaves are similar and the leaf length curve is similar to a rectangle. The leaves of "Nanjing No 1" are longer and its reverse fourth leaf is the longest with a leaf length curve approximating a triangle.

Production practices prove that the length of each leaf of one variety cultivated in one particular region remains basically within a certain length, especially the lengths of the leaves on the main stem. Thus, in production, the length of the leaves can also serve as an indicator in field diagnosis of the plants.

C. Photosynthesis and Respiration in Daylight

Like other plants, 95 percent of the total dry weight of paddy rice are photosynthetic products. Photosynthesis is the absorption and utilization of the energy of light by chloroplasts and the process of converting carbon dioxide and water into organic substances rich in energy. Its chemical process can be represented by the following simplified equation:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{2H_2O} \xrightarrow[\text{chloroplast}]{\text{light}} \underset{\text{carbohydrates}}{(CH_2O)} + \underset{\text{oxygen}}{O_2} + \underset{\text{water}}{H_2O}$$

In the above equation, (CH_2O) represents a carbohydrate, or more accurately, it should be represented by (CH_2O), where n represents a multiple of the carbohydrate molecule $(CH_2O)_n$, where n represents a multiple of the carbohydrate molecule (CH_2O). For example, in glucose $(C_6H_{12}O_6)$, n is 6.

It should be pointed out that the above equation is a general reaction equation. From present understanding, the total process of photosynthesis should at least include four sub-processes:

(1) Photolysis of water: $H_2O \xrightarrow[\text{chloroplast}]{\text{light}} 2[h] + \frac{1}{2}O_2$

ability of assimilation

(2) Formation of the capability of reduction:

$$\underset{\text{oxidizing coenzyme II}}{NADP + 2\,[H]} \xrightarrow[\text{chloroplast}]{\text{light}} \underset{\text{Reducing coenzyme II}}{NADPH_2}$$

(3) Photosynthetic phosphrylation:

$$\underset{\text{adenosine}}{ADP} + \underset{\text{inorganic phosphorus}}{P_i} \xrightarrow[\text{chloroplast}]{\text{light}} \underset{\text{adenosine triphosphate}}{ATP}$$

(4) Fixation of carbon dioxide:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{adenosine triphosphate}}{ATP} + \underset{\text{reducing coenzyme II}}{NADPH_2} + 2H_2O \xrightarrow[\text{chloroplast}]{} \underset{\text{carbohydrates}}{(CH_2O)} +$$

$$\text{NADP} \quad + \quad \text{ADP} \quad + \; P_i \; + \; H_2O \; + \; O_2$$

oxidizing coenzyme II   adenosine   water   oxygen

inorganic phosphorus

The total process of photosynthesis expressed above can be illustrated diagrammatically in Diagram 78:

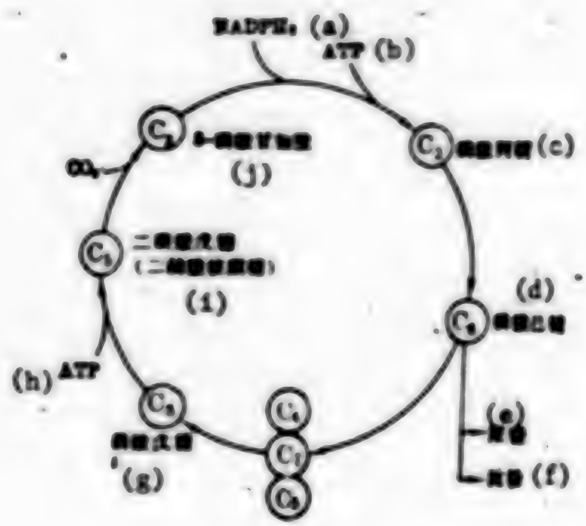


Diagram 78. Carbon Cycle in Photosynthesis (Calvin's Carbon Cycle)

Key:
(a) $NADPH_2$
(b) ATP
(c) C_3 phosphotriose
(d) C_6 phosphohexose
(e) sucrose
(f) starch
(g) phosphopentose
(h) ATP
(i) diphosphopentose (diphosphoriboketose)
(j) 3-phosphoglyceric acid

During the mid-1960s, some biologists studied the carbon dioxide assimilation process in such crops as sugar cane and corn which have an especially strong photosynthesis. They discovered that the initial products of carbon dioxide fixation were different from those produced in paddy rice and soybeans. The products included not only 3-phosphoglyceric acid (three carbon atoms) but also oxaloacetic acid and malic acid (four carbon atoms). Because the initial products were four carbon compounds, this path was named C_4-dicarboxylic acid pathway or Hatch-Slack pathway, illustrated in Diagram 79.

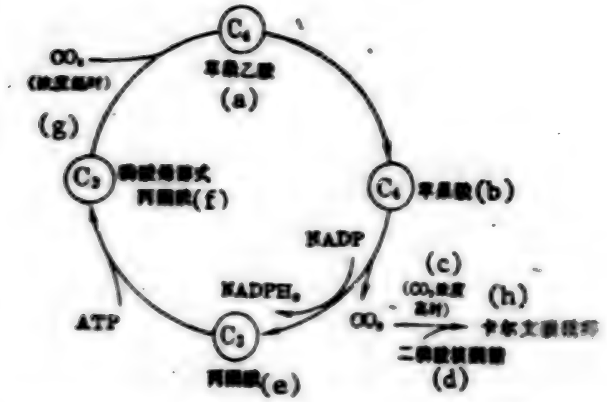


Diagram 79. C_4 - dicarboxylic Acid Pathway (Hatch-Slack Pathway)

Key: (a) oxaloacetic acid
(b) malic acid
(c) high concentration
(d) diphosphoriboketose
(e) pyruvic acid
(f) phosphoalkene alcoholic pyruvic acid
(g) low concentration
(h) Calvin Carbon Cycle

Since paddy rice, wheat and soybeans assimilate carbon dioxide by the Calvin carbon cycle to produce three carbon compounds initially (3-phosphoglyceric acid) and the rate of replenishment of carbon dioxide is high (about 50 to 100 ppm), respiration during daylight can be clearly measured. Therefore, these plants are called C_3 plants or daylight respiration plants. Corn and sugar cane also assimilate carbon dioxide via the C_4-dicarboxylic acid pathway, thus their initial products are four carbon compounds (oxaloacetic acid and malic acid). Their replenishment of carbon dioxide is low and their respiration in daylight is low, almost undetectable; therefore, they are called C_4 plants or non-daylight respiring plants.

Respiration during daylight means the process of consuming oxygen and releasing carbon dioxide simultaneously with photosynthesis under daylight conditions. Respiration during daylight is not a simple reverse of photosynthesis. It is a series of reactions closely related to photosynthesis (Diagram 80). The basic matter of respiration in daylight is ethanolic acid (glycolic acid). It is converted from the intermediate product (diphosphoriboketose) in the Calvin cycle. When ethanolic acid is produced in the chloroplast, it moves into the superoxidized bodies and under the action of ethanolic acid oxidase, it is oxidized to aldehyde acid and super hydroxide. This is the process of oxygen intake during daylight. Aldehyde acid takes on an amino group under the action of aminomutase to become glycine. Two glycine molecules fuse in the mitochondrium to form one molecule of serine and release carbon dioxide and ammonia. After serine formed in the mitochondrium moves into the superoxide bodies, it is catalyzed by aminomutase, causing

the amino group in the serine to change position, forming hydroxypyruvic acid. The hydroxypyruvic acid is reduced by the hydroxypyruvic acid reductase to glyceric acid, losing one molecule of reducing coenzyme I ($NADH_2$). Glyceric acid, by the action of the catalytic glyceric acid enzyme, expends one molecule of ATP, converting into 3-phosphoglyceric acid and reenters the photosynthetic carbon cycle.

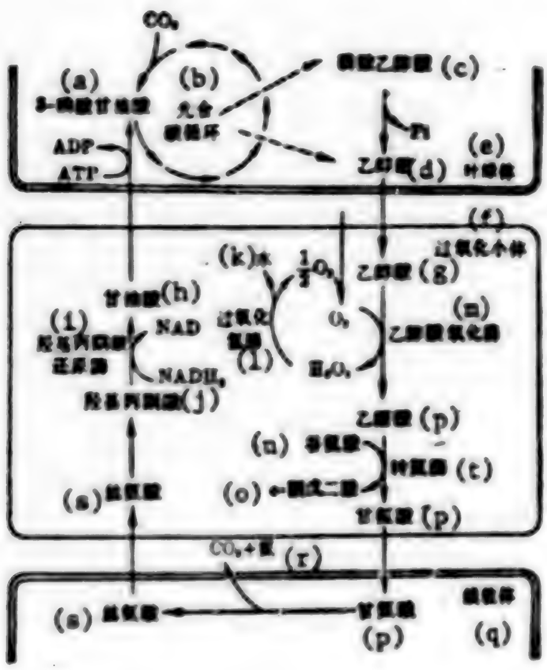


Diagram 80. Glycolic Acid Pathway

Key:		
	(a) 3-phosphoglyceric acid	(k) water
	(b) photosynthetic carbon cycle	(l) superoxidase
	(c) phosphoglycolic acid	(m) glycolic acid oxidase
	(d) glycolic acid	(n) glutamic acid
	(e) chloroplast	(o) α-ketoglutaric acid
	(f) superoxide microbody	(p) glycine
	(g) glycolic acid	(q) mitochondrium
	(h) glyceric acid	(r) ammonia
	(i) hydroxypyruvic acid	(s) serine
	(j) hydroxypyruvic acid reductase	(t) aminomutase

Since paddy rice belongs to the C_3 plants, it expends a lot of energy during the process of respiring during daylight. The amount of carbon dioxide released during respiration in daylight often amounts to over one third of the amount of carbon dioxide assimilated by photosynthesis. Thus, the pure photosynthetic strength and the speed of growth are all weaker than

C_4 plants such as corn (Table 97). Therefore, it is generally believed that respiration during daylight is unfavorable to increasing the yield of crops. A method to explore the potential of paddy rice to increase its yield is to reduce the amount of respiration under light by various means, raise the efficiency of photosynthesis and thus increase the yield. At present the work in selecting and screening varieties with low respiration activities during daylight is being done at home and abroad.

Table 97. Comparison of the Pure Photosynthetic Strength and Speed of Growth of Such C_4 Plants as Corn and Such C_3 Plants as Paddy Rice

Crop type		Pure photosynthetic strength (CO_2 milligram/decimeter^2/hour)	Speed of growth (dry weight gram/field meter^2/cycle
C_3 plants	paddy rice	12 ~ 30	--
	wheat	17 ~ 31	--
	tobacco	16 ~ 21	25
C_4 plants	corn	46 ~ 63	47
	sorghum	55	43
	sugar cane	42 ~ 49	50

Table 80 shows ethanolic acid oxidase is a specialized enzyme in respiration during daylight. Thus, the activeness of this enzyme is often taken as an indicator of the strength of daylight respiration. Studies indicate high yielding paddy rice varieties (such as "Guangluai No 4") and hybrid paddy rice all possess a less active ethanolic acid oxidase and this may be one reason for their high yields.

Table 98. Activity of Ethanolic Acid Oxidase of Several C_4 Plants and Paddy Rice Varieties (Unit: O_2 microliter/dry weight gram·hour) (Guangdong Agriculture and Forestry Academy, 1974)

C_4 Plants	Paddy rice varieties
Corn 1644	Guangluai No 4 2164
Sugar cane 848	Nanzao 2920
Sorghum 1174	Zhenzhuai 2934
	Guangerai 2972

Table 99. Comparison of Photosynthetic Strength and Respiration Strength Under Light of Hybrid Rice and the Sterile and Restorer Lines (Shanghai Plant Physiology Institute, Photosynthesis Laboratory et al, 1977)

品种 (a)	乙醇酸氧化酶相对活力(%)(移栽期) (b)	二氧化碳补偿点(ppm)(抽穗扬花期) (c)	光合强度(干重毫克/分米²/小时)(扬花期) (d)
南优3号(杂交种) (e)	63.2	76	15.6
国际661(恢复系) (f)	90.8	80	10.1
二九南1号(不育系) (g)	79.0	66	11.2

Remark: Erjiunan No 1 (sterile) x Guoji 661 (restorer line)
↓
Nanyou No 3

Key:
(a) Varieties
(b) Ethanolic acid oxidase relative activity (%) (at transplanting time)
(c) Replenishment point of carbon dioxide (ppm) (heading and flowering time)
(d) Strength of photosynthesis (dry weight milligram/decimeter^2/ /hour (flowering time)
(e) Nanyou No 3 (hybrid)
(f) [International] Gauji 661 (restorer line)
(g) Erjiunan No 1 (sterile line)

In addition, studies at home and abroad are being conducted at present on the development of chemical agents that suppress daylight respiration. Reports indicate chemical compounds of α-hydroxysulphates (such as α-hydroxy-2-pyridol methane sulphate (HPMS) etc), sodium hydrosulphite and indole acetic acid (IAA) can suppress the glycolic acid (ethanolic acid) oxidase. Isonicotinic hydrazide (INH) can suppress the reaction of glycine ⟶ serine. Atlangen (?) (2-chloro-4-ethylamino-6 isopropylamino-1,3,5-trinitrobenzene) can suppress formation of ethanolic acid. Although the above chemical agents are not yet suitable for actual application in production, further in-depth study to seek new chemical agents to suppress daylight respiration is a new path towards increasing paddy rice yield.

D. External Causes Affecting Photosynthesis

In the large field, intensity of light, supply of carbon dioxide, the angle of incidence of light upon the leaves, temperature and nutrition are factors that affect the intensity of photosynthesis of the leaves.

1. Intensity of Light

Light is the source of energy for photosynthesis. It affects photosynthesis greatly. The intensity of photosynthesis of the leaves can be measured only when the intensity of light reaches a certain level. This level is exactly the level at which the intensity of photosynthesis and the intensity of respiration are equal. At this time, the intensity of light is called the light replenishment point. When the intensity of light is greater than this level, the intensity of photosynthesis increases along with increases in the intensity of light. At first the increases are related linearly. But, after exceeding a certain range, increases in the intensity of photosynthesis slow and finally reach a definite limit. The intensity of light at this limit is called the light saturation point (The light saturation point of the single leaf of the paddy rice plant is between 40,000 and 50,000 meter-candles). When the intensity of light surpasses this limit, the intensity of photosynthesis does not increase and sometimes even reduces. The light replenishment point and the light saturation point are the lower and upper limits of the intensity of light demanded by photosynthesis of the leaves. Therefore they serve as two important indicators of the characteristics of the need for light by the paddy rice leaf. The relationship between intensity of light and changes in the intensity of photosynthesis is illustrated in Diagram 81.

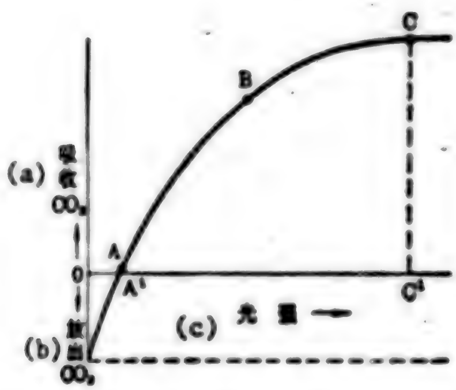


Diagram 81. Light Intensity of Leaves of Paddy Rice and Photosynthesis Curve.

A^1_1 is light replenishment point
C^1 is light saturation point

Key: (a) absorption of CO_2 (c) Intensity of light
(b) release of CO_2

The curve in the diagram above can be called the light intensity curve of photosynthesis of the paddy rice leaf or the leaf's light requirement curve. Point A is the pure photosynthetic intensity at light replenishment point A', which equals zero. Point C is the pure photosynthetic strength at light

saturation point C' at its greatest value. Line AB which approximates a straight line marks a higher efficiency of utilization of light intensity. Line BC which approximates a horizontal line indicates the disproportionate increase of photosynthesis as the intensity of light increases, but at this time photosynthesis is still strong and this benefits production. The part of the intensity of light that suppresses the light saturation point cannot be utilized by the paddy rice plant and such intensities of light may even cause reverse effects.

During the period between transplanting and peak tillering, the stronger the intensity of light the more the plant can assimilate. Within an intensity of 80,000 meter-candles, the light saturation point will not be reached.

In a rice field with an overly prosperous growth, the intensity of light at the base of the colony often drops to lower than 1000 meter-candles or below 500 meter-candles. At this time, the leaves at the lower parts of the colony cannot produce assimilated substances nor even consume nutrients for respiration. At the same time, the leaves at the lower positions die and the number of green leaves on the plant reduces. This creates many adverse effects upon the healthy growth of the rice plant and the formation of yield.

2. Supply of Carbon Dioxide

Carbon dioxide is the raw material of photosynthesis. It also directly affects the intensity of photosynthesis. The content of carbon dioxide in the air is generally 0.03 percent by volume. This is not enough for photosynthesis and especially insufficient for high yielding fields, thus carbon dioxide has become a major problem in increasing yield. When the concentration of carbon dioxide drops to 0.005 percent to 0.01 percent (50 to 100 ppm), the leaves cannot absorb carbon dioxide for photosynthesis. This limit is called the carbon dioxide replenishment point. When the concentration of carbon dioxide is greater than this limit, the intensity of photosynthesis rises linearly. But when the rise reaches a definite limit, the speed of increase of photosynthesis slows and finally stabilizes at a certain limit and the intensity of photosynthesis does not increase along with increases in carbon dioxide. This limit of the concentration of carbon dioxide is called the carbon dioxide saturation point (Diagram 82).

Experiments have proven that when the radiation from the sun is between 550 to 660 calories/square centimeter·day and when the concentration of carbon dioxide in the air increases to 0.24 percent, the per mu yield of paddy rice can increase to 2520 jin, a 90 percent increase in yield over the control. Another group of experiments also arrived at similar results. Under a sunlight of 400 to 500 calories/square centimeter·day and when the concentration of carbon dioxide was increased to 0.09 percent before heading, the paddy rice yield increased by 29 percent. If the concentration of carbon dioxide was increased after heading, the yield could be increased

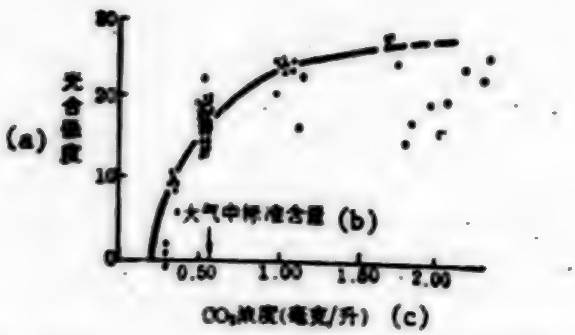


Diagram 82. CO_2 Concentration and its Relationship with Photosynthetic Intensity of the Leaves

Note: o "Qianbenxu" was cultivated in a flower pot for experiment, data measured under saturated light conditions.

• "Nonglin No 37" was cultivated in the field.

Key: (a) Photosynthetic intensity
(b) standard content in atmosphere
(c) CO_2 concentration (milligram/liter)

by 21 percent. The above experiments were conducted in plastic green houses or under thin plastic sheets. The experiments showed that carbon dioxide greatly affected the potential for increasing the yield of paddy rice. But, the problem concerning increasing the concentration of carbon dioxide in the large field is still not solved. At present, the only way is to increase the concentration of carbon dioxide slightly by means of cultivation.

First is the selection of the direction of the rows so that wind can easily pass through the plants. When the paddy rice plant undergoes photosynthesis, it takes in a lot of carbon dioxide. In general, every 100 square centimeters of surface area of leaves absorbs 20 to 30 milligrams of carbon dioxide per hour. Calculating at 6 hours a day and an average leaf surface area coefficient of 5 for the entire period of growth, each mu of paddy rice plants needs to absorb 40 to 60 jin of carbon dioxide per day, equivalent to the content of carbon dioxide in 8 to 13 cubic meters of air. Relying only on the dispersion of carbon dioxide in the air will not satisfy the large need for carbon dioxide by the paddy rice plants. Especially at noon when the intensity of photosynthesis is stronger, the amount of carbon dioxide among the plants will be deficient. Thus, the rows must be arranged in a proper direction according to local conditions so that aeration through the rows is good and the amount of carbon dioxide in the air can be replenished to the photosynthetic level. Aeration also stimulates and increases the intensity of photosynthesis.

Second is to deepen the plowing layer and increase organic fertilizers so that the number of microorganisms in the soil will increase, their activity to decompose organic substances in the soil will increase and the release carbon dioxide will intensify. Part of the carbon dioxide released in the soil is dissolved in the soil's solutions for the roots to absorb and the rest of the carbon dioxide is released into the air for the leaves to utilize. Measurements show the speed with which carbon dioxide is supplied by arid soils is between 0.13 and 2.20 grams/square meter·hour. The speed with which carbon dioxide is released into the air from the paddy rice soil is smaller than 0.1 gram/square meter·hour because the soil is insulated by the layer of water. Therefore drying the paddy rice field is beneficial to the release of carbon dioxide from the soil into the air. Drying the field can also increase the amount of oxygen in the soil, stimulate decomposition of organic substances and release carbon dioxide.

3. Moisture

Moisture is also a direct raw material for photosynthesis. Insufficient moisture will prevent stomates from opening and carbon dioxide will not enter the plant easily, affecting the normal process of photosynthesis. At the same time, insufficient moisture also hinders transportation of inorganic salts and synthesis of organic substances, thus indirectly affecting photosynthesis.

4. Angle of incidence of light upon the leaves

The front and the back of the leaf can both conduct photosynthesis almost without any difference. Hence, an erect leaf will visibly increase the efficiency of utilization of light energy and thus increase yield. This is because an erect leaf receives light well and better permeability of light increases the intensity of photosynthesis of the leaves at the middle and lower parts of the plant. Conversely, when the upper leaves droop and create a shade over the leaves at the middle and lower parts of the plant, the intensity of photosynthesis drops. Thus, the ideal plant type should be a plant with erect upper leaves at a small angle from the stem and gradually expansive lower leaves.

On sunny days, the rice field receives stronger direct sunlight and has sufficient scattered light. The angle of incidence of light upon the leaves is either at right angle or level. The intensity of photosynthesis is greater. Parallel light incident upon the leaves will lower the intensity of photosynthesis (Diagram 83).

Key: (a) right angle
(b) level
(c) parallel

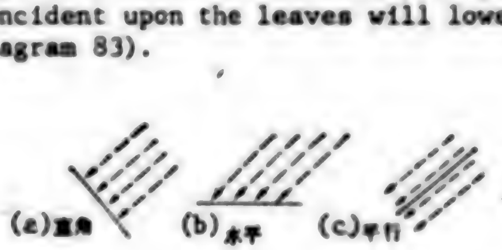


Diagram 83. Different Angles of Incidence of Light on the Paddy Rice Leaf

The length of leaves varies greater than the width. The length of leaves is closely related to the angle at which the leaves are attached to the stem. Long leaves droop and short, small leaves are erect. Short stems with erect leaves allow light to shine upon the leaves at the middle and lower parts of the plant, therefore short stem plants can be planted more densely. For example, "Kezi No 6" variety has a clustered plant type and the angles of leaves on the stem are small. The horizontal cross section of the leaves is shaped like a nail, benefiting an increase in the utilization of light energy. Conversely, curled leaves have a poor ability of assimilation and especially in a colony this becomes worse. Matsushima (1964) determined that the amount of assimilation of the single plant with erect leaves surpasses the amount of assimilation of the single plant with curled leaves by 9.3 (CO_2 milligram/10 minutes) while the assimilated amount of a colony of plants with erect leaves surpasses that with curled leaves by 54.3 (Table 100). Thus, in production, plants should be short, narrow and erect. This shape benefits utilization of light energy and raises photosynthesis of the colony.

Table 100. Relationship Between Amount of Assimilation of Carbon and Different Angles of Incidence of Light on Leaves

	(a)单 株		(b)群 体	
	叶片直立 (c)	叶片弯曲 (d)	叶片直立 (c)	叶片弯曲 (d)
(e)同 化 量 (CO_2毫克/10分钟)	160.9	151.6	158.2	103.9
同化量比率 (f) (%)	100	94.1	100	65.7

Key: (a) Single plant
(b) Colony
(c) Erect leaf
(d) curled leaf
(e) Assimilated amount (CO_2 milligram/10 minutes)
(f) Percentage of amount assimilated (%)

5. Temperature

The effect of temperature upon photosynthesis of the paddy rice plant is related to the intensity of light. Yamada et al, showed in their studies that when light is sufficient and the temperature is between 18°C and 34°C, the fluctuation in temperature affects the amount of photosynthesis very slightly. Only when light is weak and the temperatures have risen will the intensity of photosynthesis visibly increase. If the temperatures are overly high, surpassing 35°C, photosynthesis will be adversely affected (Daigram 84).

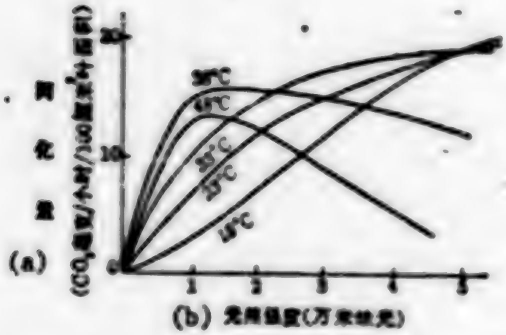


Diagram 84. Combined Effect of Light and Temperature on Photosynthesis of Paddy Rice Leaves

Key: (a) Amount assimilated (CO_2 milligram/hour/100 centimeter^2 leaf surface area)
(b) Light intensity (10,000 meter-candles)

In the middle and lower reaches of the Chang Jiang region during the fruiting period of late season rice, sunny days are plentiful, light is sufficient and the nighttime temperatures are lower. These conditions are beneficial to the accumulation of assimilated products and stimulate photosynthesis. Therefore, the 1000 grain weight of late season rice is higher. Another example is when a thin plastic sheet is used to cover the seedlings during early spring, temperatures in the seedbed can be retained when the outside temperatures are low and the weather is damp and rainy. The sheet not only protects the seedlings against cold but when light is weakened during cloudy days, the temperature in the seed bed is raised. This benefits photosynthesis of the seedlings.

6. Nutrition

Among the nutritional elements of nitrogen, phosphorus and potassium, nitrogen has the closest relationship to photosynthesis. Under ordinary conditions, the content of nitrogen in the leaves rises and the photosynthetic capabilities of plants within a unit area begin to rise 3 days after sidedressing of nitrogen fertilizers but after 8 to 14 days, the effect of nitrogen upon photosynthesis gradually reduces. Studies indicate when the content of nitrogen is between 3.26 percent and 6.42 percent of the amount of dry substances, the intensity of photosynthesis increases linearly with the increase in the amount of nitrogen. Phosphorus can stimulate conversion of photosynthetic products. Potassium and the synthesis of carbohydrates are related to transportation of nutrients and serve to increase the intensity of photosynthesis.

II. Utilization of Energy of Light in a Colony

A. Analysis of the Utilization of Light Energy by the Paddy Rice Colony

Not all of the energy of light from the sun shining upon the paddy rice leaves is absorbed by the leaves. Some of the light energy is reflected, scattered and lost in space. Some light shines through the leaves and is not absorbed. The amount of light energy being reflected varies according to the degree of reflectance of the cutin layer on the surface of the leaves and the angle of the leaves towards the sun. The amount of light energy permeating the leaves is determined by the thickness and the color of the leaves. The light energy from the sun that is absorbed by the leaves is mostly converted into thermal energy. This energy is consumed during evaporation which changes moisture into steam (1 gram of moisture requires 539 calories to evaporate into steam) or is lost in the air again after raising the temperature of the leaves (the temperature of the leaves is generally higher than the atmospheric temperature by 1°C to 3°C). Thus, of the light energy from the sun absorbed by the leaves, only a small portion is used in photosynthesis. The following outlines the utilization and loss of solar light energy upon the leaves:

- Sun light 100%
  - Visible light
    - Reflected-5.0%
    - Permeated-2.5%
    - Absorbed-42.5%
      - Lost in evaporation——40%
      - Lost in heat scattering——1.5% to 2.0%
      - Used in photosynthesis——0.5% to 1.0%
  - Infra light 50%
    - Reflected—22.5%
    - Permeated—15.0%
    - Absorbed—12.5% (all lost in evaporation and heat scattering)

Since the paddy rice field is a colony, some of the sunlight shines on the paddy rice plants and some shines on the field. Some shines directly and some is diffused. On the same plant, the upper layer of paddy rice leaves receives strong light and the bottom layer receives weak light. Thus, the colony of paddy rice utilizes light energy in varied conditions classified as leakage of light, reflection of light and absorption of light.

1. Leakage of light

Different fields or different growth stages in the same field have different percentages of light leakage. Prosperous growth of paddy rice plants allows a minimal leakage of light while short and small plants allow more

leakage. The range of light leakage during the early period of tillering is between 40 percent and 70 percent (determined by the growth of the paddy rice plants, taking the sunlight shining on the surface of the field as 1 J percent). During the latter period of tillering, the percentage of light leakage is between 10 percent and 50 percent. During the jointing and panicle differentiation stages, it is between 1 percent and 20 percent, and during the heading period between 0.3 percent and 0.5 percent. After heading the leaves begin to wither and the percentage of the leakage of light slightly increases.

In fields in which growth is normal, the leakage of light after closing of the rows is minimal. In fields in which fertilization is insufficient and in infertile fields, closing of the rows occurs very late or the rows do not close during the life of the plant. Here, the leakage of light is great, reaching between 50 percent and 80 percent during the early period and above 10 percent during the latter period of growth. This is a tremendous waste of light energy.

2. Reflection of light

In fields with different types of growth or during different growth periods in the same field, the change in the percentage of reflected light is small, only between 4 percent and 6 percent. The reason may be because the ability to reflect visible light by the surface of the paddy rice plant is close to that by the surface of water in the rice field.

3. Absorption of light

Besides reflection and leakage of light, the light that shines upon the rice field is absorbed by the plant. The percentage of light being absorbed in the rice field is inversely related to the percentage of leakage of light. Minimal leakage of light means more light is being absorbed and a lot of leakage of light means less is absorbed. Plants that grow poorly absorb lesslight and plants that grow well absorb more light. The percentage of absorption of light of high yielding fields varies according to different growth periods. It is 85 percent during the latter period of tillering and over 95 percent during heading. All of the light in the paddy rice colony is absorbed by the leaves on the stem (mainly by the leaf blade), forming a "photosynthetic level." The distribution of light over the photosynthetic level is mainly determined by the characteristics of light permeability of the leaves (such as the color of the leaves being dark or light and the thickness of the leaves), the angle at which the leaves are attached to the stem and the height of the colony. Yin Hongzhang (3009 1347 4545) et al (1959) determined that in the paddy rice colony, the intensity of light drops rapidly from the upper part to the lower part of the plants and becomes very weak at the middle and lower parts of the plants (Diagram 85). Thus, the upper leaves affect distribution of light energy greatly. In cultivation, the photosynthetic level during the early period of growth is thin and the upper leaves can be slightly curled. During the middle period

of rapid development of the colony, competition for light intensifies. At this time the upper leaves should be short and erect and drooping leaves should not be allowed so that the light source for the middle and lower leaves can be improved.

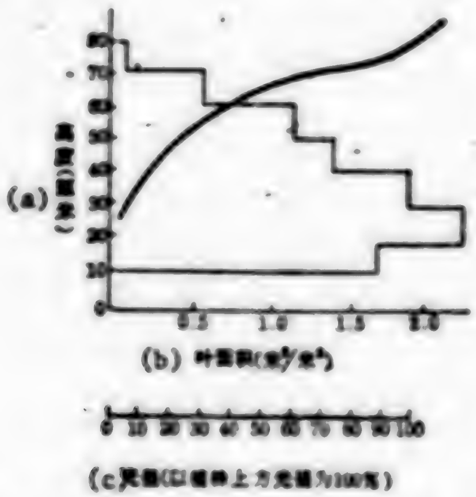


Diagram 85. Distribution of Light Intensity in Paddy Rice Colony

* In the diagram, the curve represents the relationship between the height of the colony and the intensity of light. The steps represent the relationship between the surface area of the leaf and the photosynthetic level from a certain height to a certain height in the colony. The leaf surface area ($meter^2/meter^2$) represents surface area of leaves within each $meter^2$ of the photosynthetic level from a certain height to a certain height in the colony.

Key: (a) height (centimeter)
(b) leaf surface area ($meter^2/meter^2$)
(c) Light intensity (light intensity at top of plant is 100 percent)

B. Reasonable Increase of the Surface Area of Leaves to Increase Utilization of Energy of Light by the Colony

In production in the large field, the surface area of leaves of the paddy rice colony is generally expressed by the leaf surface area coefficient [?leaf area index], i.e., the ratio of the total surface area of green leaves to the total land area. Many measures to increase yield, including reasonably dense planting and management of fertilization and irrigation, are effective in increasing the surface area of leaves. Studies done by the Shanghai Plant Physiology Institute indicated that within a definite area, the greater the surface area of the leaves of the colony during the growth period of paddy rice the higher the efficiency of utilization of light energy. At a correlation coefficient of $r = 0.6528$, the utilization of light energy (y) and the leaf surface area coefficient are linearly regressive, i.e., $y = 0.2792 + 0.2426x$. When the leaf surface area coefficient

increases by 1, the percentage of utilization of light energy increases by 0.24 percent. When the leaf surface area coefficient reaches between 7 and 8, the same increases take place. Lin Shicheng [2651 0013 2052] (1963) reached similar results in his study (Diagram 86). The results indicate the increase in the dry weight of paddy rice follows the increase in the surface area of the leaves.

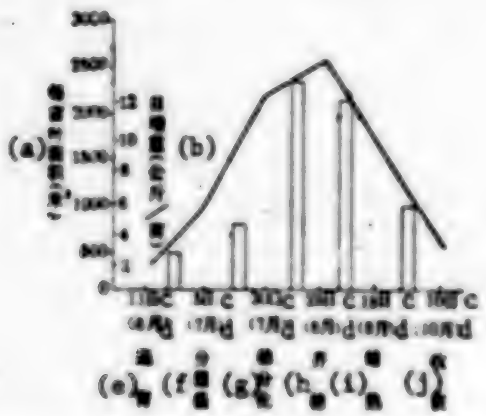


Diagram 86. Relationship Between Daily Gain in Weight of Dry Substance and Surface of Leaves

Key: (a) surface area of leaves per mu (meter^2)
(b) daily gain in weight (jin/mu)
(c) day
(d) month
(e) greening
(f) tillering peak
(g) panicle differentiation
(h) full heading
(i) waxy ripe
(j) harvest

In addition, concerned units clearly showed in their studies (Diagram 87, Table 101) that during the entire growth period, accumulation of dry substances and their weight are different for paddy rice colonies with different leaf surface area coefficients. Colonies with large leaf surface areas produce heavy dry weights. Conversely, colonies with small surface areas produce light dry weights. The first colonies produced higher yields than the second colonies.

From the point of view of physiological analysis, it is generally believed that the surface area of leaves that allows the percentage of utilization of light energy in a colony to reach the maximum (represented by increases in dry weight) is the most suitable leaf surface area. When the area of the leaves is greater than this value, the dry weight of the colony does not increase much and may even lessen. When the area of the leaves in the colony is smaller than this value, the dry weight increases as the area of the surface of the leaves increases. At present, the most suitable leaf

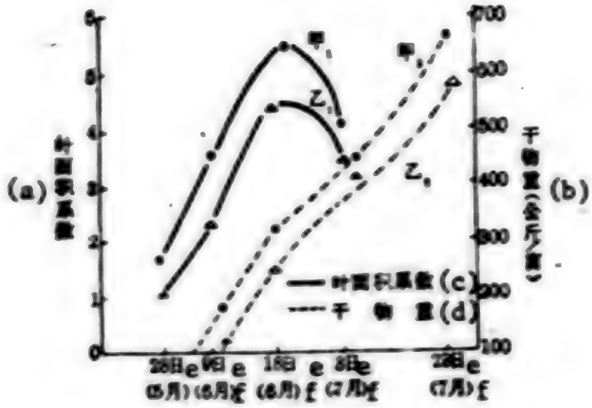


Diagram 87. Relationship Between Dry Weight and Surface Area of Leaves of Early Rice in the Triple Cropping System

Key: (a) leaf surface area coefficient
(b) dry weight (jin/mu)
(c) leaf surface area coefficient
(d) dry weight of substance
(e) day
(f) month

Table 101. Examples of Leaf Area Activity of Fields Yielding 1000 Jin

类型 (a)	品种 (b)	产量 (c) (斤/亩)	(d) 叶面积动态(以叶面积系数表示) 返青 (e)	分蘖 (f)	分蘖高峰 (g)	(h)	(i)	(j)
(k) 早稻	(l) 广陆矮4号	1022	0.79	1.6	—	6.6	7.2	6.2
(m) 中稻	(n) 京引 101	1140	—	2.0	3.4	8.9	7.7	—
(o) 晚稻	(p) 苏粳2号	1236	—	1.8	2.6	9.2	8.2	—

Key: (a) type
(b) variety
(c) yield (jin/mu)
(d) activity of leaf surface area (represented by leaf area coefficient)
(e) greening
(f) tillering
(g) heading
(h) waxy ripe
(i) tillering peak
(j) spikelet differentiation
(k) early rice
(l) Guangluai No 4
(m) Intermediate rice
(n) Jingyin 101
(o) late rice
(p) Sugeng No 2

surface coefficient of the paddy rice varieties now used in production is between 4 and 6. In production, it is required that the early period of double season rice should grow in a big way so that the leaf surface area

coefficient of the colony can be increased as rapidly as possible to this value, held stable during the middle growth period (in production, control of irrigation and fertilization are such measures) so that the leaf surface co fficient will not surpass this level, and kept from withering early during the latter period (such as strategically applying pellet fertilizers, creating aerate conditions to nourish the roots so that the roots can preserve and extend the functional period of the leaves). Simply stated, the objective is to maintain the leaf surface area coefficient at this most suitable level.

C. Relationship Between Surface Area of Leaves and Net Assimilation by Photosynthesis

When the leaves perform photosynthesis, part of the organic substances synthesized are consumed by respiratory and metabolic functions. The actually measured dry weight does not represent the total amount of products of photosynthesis but the amount of substances less the amount consumed in respiration, called the net assimilation percentage.

Net assimilation percentage (dry weight gram/meter^2/day) =

$$= \frac{W_2 - W_1}{\frac{(S_1 + S_2)}{2} \times \text{number of days}}$$

In the formula: W_1 and W_2 represent dry weights measured before and after and S_1 and S_2 represent the leaf surface area measured before and after.

The net assimilation percentage is the average value of the efficiency of photosynthesis at each level of leaves. When the leaf surface coefficient is small, the plants do not block each other and all the leaves are basically effective leaf surfaces, therefore the net assimilation percentage is higher. As the colony develops, the surface area of the leaves increases and as the leaves begin to block each other the light conditions of some leaves become poor and the efficiency of photosynthesis of some leaves reduces. At this time, an increase in the surface area of leaves will bring about a reduction in the net assimilation percentage.

Reasonably dense planting in a sense means solving this contradiction between the increase in leaf surface area and the reduction in the net assimilation percentage through measures of cultivation. This is so that the total increase in dry weight due to the increase in the surface area of the leaves will surpass the loss created by the reduction in net assimilation percentage because of any overly increase in leaf surface area. Otherwise, if the increase in total dry weight cannot make up for the loss in net

assimilation percentage due to an over expansion of the surface area of the leaves, then the planting density would not be considered reasonable.

The above shows that it is not always better to have a larger surface area of leaves. When the surface area of leaves is overly expansive, the conditions of light among plants will become poor, affecting many aspects of photosynthesis and causing low yields. Thus, there should be a more appropriate range for the surface area of leaves in production, i.e., a most suitable leaf surface area coefficient (Daigram 88). Within this range, light energy can be fully utilized, greater percentages of net assimilation can be realized and higher yields can be produced.

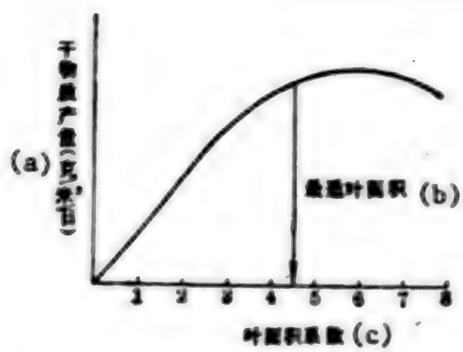


Diagram 88. Most Suitable Leaf Surface Area for Paddy Rice

Key: (a) Yield of dry substance (gram/meter^2/day)
(b) Most suitable leaf surface area
(c) Leaf surface area coefficient

Concerned units have introduced data concerning the difference in the ranges of leaf surface areas for different paddy rice types and varieties and for different growth periods. At present, the required range of leaf surface area coefficients varies with different growth periods. In general, the leaf surface area coefficient during the tillering period is between 3.0 and 3.5, that during the jointing period is between 4 and 5, that during the panicle bearing period is between 6 and 8, that during the period of milky ripe period is 5.5 and that during the latter period of the milky ripe period is 4.5.

D. The Function of Photosynthesis and Paddy Rice Yield

The relationship between paddy rice yield and photosynthesis can be expressed by the following formula:

Paddy rice yield = biological production x economic coefficient

The biological production = (duration of photosynthesis x surface area of photosynthesis x photosynthetic capability) -- consumption of photosynthetic products

$$\text{The economic coefficient} = \frac{\text{Economic production (weight of grains)}}{\text{Biological production (total weight of plant)}}$$

It can be seen from the above that the paddy rice yield is determined by five factors, the duration of photosynthesis, the surface area of photosynthesis, the capability of photosynthesis, the consumption of photosynthetic products and the distribution and utilization of photosynthetic products (i.e., economic coefficient). These five factors together constitute the function of photosynthesis. In general, high yields are produced when the duration of photosynthesis is long, the surface area of photosynthesis is appropriately large, the capability of photosynthesis is strong, the consumption of photosynthetic products (respiration) is small, and the distribution and utilization of photosynthetic products are reasonable. All measures to increase production are fundamentally aimed at improving the function of photosynthesis.

1. Duration of Photosynthesis

The duration of photosynthesis is mainly determined by the duration of planting of paddy rice in the year, the length of the growth period of the plants within a season, the number of hours of sunlight and the life of the leaves. In the regions south of the Chang Jiang, a single season paddy rice has been changed to double season paddy rice and the double cropping a year system has been changed to triple cropping a year. These are measures to increase the duration of photosynthesis within the year. Increase in unit area production has been realized in actual production. In production, the growth period of each crop should be extended without affecting the planting system and the arrangement of crop openings. Within one season, the early period of growth should be early and speedy so that a larger and more appropriate surface area for photosynthesis can be realized earlier. During the latter period of growth, maturation should occur while the plant is still green and alive and early withering of the leaves should be prevented. All of these measures are based upon extending the duration of photosynthesis. A lengthy duration of photosynthesis will allow more accumulation and formation of photosynthetic products and will benefit high yields.

2. Surface area of photosynthesis

The surface area of photosynthesis is the green surface area, mainly the surface area of leaves. It is the photosynthetic function most closely related to formation of yield. It affects the yield the greatest and at the same time is the easiest factor to control. Reasonable management of fertilization and irrigation and a reasonably dense planting are measures mainly to increase production by increasing the surface area of photosynthesis. But if the surface area of leaves is too large, aeration and light permeability in the colony will be affected, causing a series of problems. Thus the surface area of leaves must be appropriate. The surface area of leaves is generally expressed by the leaf surface area coefficient.

3. Capability of Photosynthesis

The capability of photosynthesis is the efficiency of photosynthesis in a unit leaf surface area. It is also an important factor that determines the amount of photosynthetic products. Light, temperature, moisture, fertilizers and the concentration of carbon dioxide all affect the capability of photosynthesis and often combine as a comprehensive factor. The capability of photosynthesis is also related to the variety of paddy rice. The capabilities of photosynthesis of high yielding paddy rice varieties and hybrid paddy rice are related to their high yield. At present, work is being done at home and abroad in selecting and screening paddy rice varieties with low respiration in daylight. This is based upon the theory of increasing the capabilities of photosynthesis by lowering respiration in daylight.

4. Consumption of Photosynthetic Products

Consumption of photosynthetic products occurs mainly during respiration. Respiration of paddy rice expends some photosynthetic products to maintain the normal and necessary life activities of the plant body. But when the temperature is too high and especially when the nighttime temperature is too high, respiration in daylight often becomes useless consumption and a wasting of photosynthetic products. Thus, to lower useless consumption during respiration is also an important aspect in exploring the potential for increasing yield of paddy rice.

5. Distribution of Photosynthetic Products

The distribution and utilization of photosynthetic products directly affect the economic coefficient. When more photosynthetic products are distributed to the grains, the economic coefficient is high (i.e., the ratio of grain to bio mass is high). The economic coefficients of short stem varieties and tall stem varieties of paddy rice are different. Studies indicate short stem varieties generally have an economic coefficient of between 0.50 and 0.63 (i.e. a grain to bio mass ratio of 1.0 to 1.7). Tall stem varieties have an economic coefficient of between 0.44 and 0.47 (the grain to bio mass ratio is 0.8 to 0.9). Thus, short stem varieties have greater capabilities of surplus yield than tall stem varieties. In addition, the economic coefficient is related to measures of cultivation.

The five functional factors of photosynthesis have their own characteristics and must be appropriately combined before high yields are possible. There are different major problems that occur under different conditions. Each of the major problems brings about a different effect. For example, in paddy rice fields of low fertility, the photosynthetic surface is small (leaves are small) and the duration of photosynthesis is short (the plant cannot germinate and develop fast during the early period and withers early during the latter period). These are the major problems. In fields where

fertilization, irrigation and planting density are good, overly large photosynthetic surface areas (the leaf surface area coefficient is too large), low capability of photosynthesis (light among the plants is weak) or a low economic coefficient can also become major problems. Thus, under different conditions, the major problems must be grasped well and solved so that the utilization of light energy by the colony of paddy rice can be raised and high yields can be realized.

III. Regulation and Structure of the High Yielding Paddy Rice Colony

Practice proves that reasonably dense planting is a major measure to raise the utilization of light energy by the colony of paddy rice. This is because it can assure that the colony will be able to develop well, provide more suitable photosynthetic surfaces and fully utilize the fertility of the soil and light energy. Thus, reasonably dense planting is also a central link in increasing unit area production.

The problem of reasonably dense planting is in actuality the problem of solving the conflict between the colony and the individual plant. Thus we must discuss in depth the structure of the colony and its regulation.

A. Structure of the Paddy Rice Colony

The problem of the structure of the paddy rice colony involves the conflict between the colony and the individual plant and the conflict between the number of panicles and the number of grains in the production structure. These are discussed below.

1. The conflict between the colony and the individual paddy rice plant.

The paddy rice colony is composed of many individual paddy rice plants. However, the characteristics of the colony is not just the simple sum of the characteristics of each of the individual plants that compose it. The colony has its own characteristics and patterns. The assembly of many individual plants causes the microclimate in the colony such as temperature, humidity, light and aeration to change and thus strongly affects the various life activities and growth and development of each individual plant. The growth and development of each individual plant in turn affects the development of the colony. This constitutes the conflict between the colony and the individual plant.

The conflict between the colony and the individual plant exists throughout the life of the paddy rice plant. In general, the microclimate within the colony does not undergo visible change during the early period of growth of the paddy rice plants because the seedlings are small and the plants are short. Therefore during this period the conflict between the individual plant and the colony is not major. During the middle and latter periods of paddy rice growth, especially during the latter period, the leaf surface area coefficient rapidly rises and light, temperature, wind and humidity all change visibly. Now, the conflict between the colony and the individual

plant sharpens. Among the factors of microclimate in the colony, light exerts the most effect upon this conflict because the series of problems concerned with whether the planting density is reasonable or not often is caused first by an insufficiency of light within the colony. Observations indicate that intensity of light at the lower part of the paddy rice plant during the peak tillering period (10 centimeters above the surface of the soil) is between 30 percent and 60 percent of natural light but during the young panicle differentiation period the intensity at the lower part is only between 4 percent and 14 percent and this drops to between 2 percent and 6 percent during the panicle bearing stage. Since paddy rice is very sensitive to light, temperatures, water and fertilizers during the middle and latter periods of growth, these factors undoubtedly affect the normal growth and development of the individual plant, the number of panicles, number of grains and even the weight of the grains.

2. The conflict between the number of panicles and the number of grains

Observations show that when the colony is small, the conflict between the number of panicles and the number of grains is not major. The yield rises along with the development of the colony and the increases in the number of panicles (Table 102). Summarizing the history of paddy rice production in the Shanghai area and the experiences of high yields of paddy rice in recent years, it can be seen that the insufficiency of the number of panicles in large field production at present is still the major problem that affects yield. Thus, many units are appropriately increasing the basic number of seedlings to increase the number of panicles upon the basis of improving the soil and increasing the application of organic fertilizers so that more visible yield can be realized.

Table 102. Relationship Between Yield and the Number of Effective Panicles of Paddy Rice

(a) 有效穗 (万/亩)	(b) 调查田块数	(c) 每穗实粒数	(d) 千粒重 (克)	(e) 产量幅度 (斤/亩)
35.0	5	36.5	27.5	600~700
38.3	12	37.2	27.1	700~800
40.6	11	39.4	26.1	800~900
44.9	7	39.3	26.9	900~1000

Note: Variety examined was "Jianongxitong" (late season rice)

Key: (a) effective panicles (10,000/mu)
(b) fields inspected
(c) number of full grains per panicle
(d) 1000 grain weight (gram)
(e) range of yield (jin/mu)

But, as the level of production rises and when the development of the colony surpasses a certain degree, the microclimate within the colony worsens and the development of the individual plant is suppressed, thus causing the yield to drop (Table 103).

Table 103. Relationship Between Yield and Number of Grains and Number of Panicles of Paddy Rice

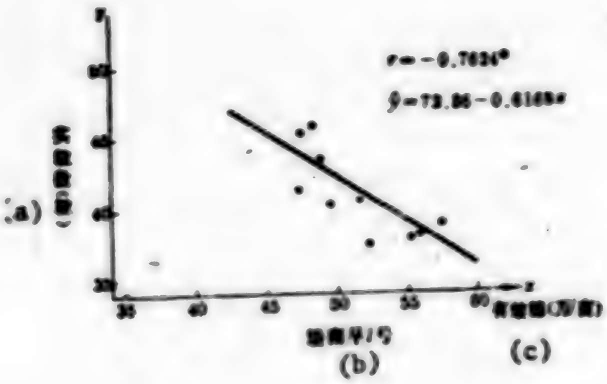
有效穗数 (万/亩) (a)	每穗总粒数 (b)	每穗实粒数 (c)	千粒重 (克) (d)	估产 (斤/亩) (e)	考察田块 (f)
27.37	53.30	44.90	26.20	644	1
33.29	46.45	41.90	27.84	768	15
37.63	44.33	39.69	26.96	802	37
42.55	40.81	36.52	27.37	847	30
47.22	40.98	36.01	27.68	841	19
51.78	34.72	31.36	26.28	917	6
57.50	36.4	27.86	27.99	895	4

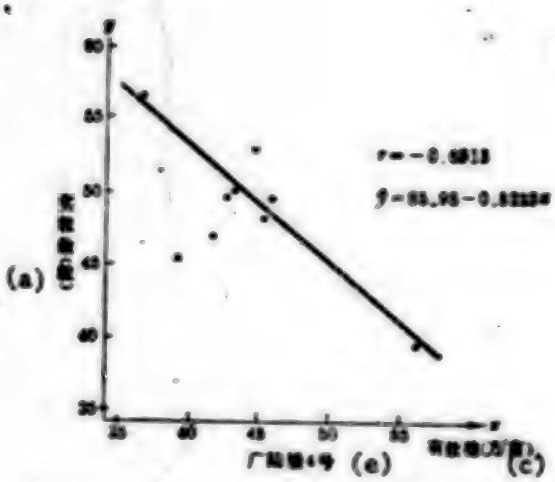
Key:
(a) Number of effective panicles (10,000/mu)
(b) Total number of grains per panicle
(c) Number of full grains per panicle
(d) 100 grain weight (gram)
(e) Estimated yield jin/mu
(f) Fields inspected

Table 103 shows that the development of the colony leads to a reduction in production because an increase in the number of panicles causes a change in yield. The increase in the number of panicles cannot make up for the reduction in the number of filled grains, thus leading to a reduction in yield.

The relationship between the increase in the number of panicles and the reduction in the number of filled grains was analyzed by the Shanghai Municipal Agricultural Science Academy (1975). A negative correlation between the increase in the number of effective panicles and the reduction in the number of filled grains of each panicle of the three varieties of early rice clearly existed (Diagram 89). Of the varieties, the correlation coefficient of "Ainanzao No 1" was 4 = -0.7624*. The number of filled grains per panicle (6) and the number of effective panicles (x) were linearly regressive, i.e., when the number of effective panicles in a mu was increased by 10,000, the number of filled grains per panicle reduced by 0.6 grain. The correlation coefficient of "Ainanzao No 39" was 4 = -0.8444**, and y and x were linearly regressive, i.e., when the number of effective panicles per mu increased by 10,000, the number of filled grains per panicle reduced by 0.6 grain. The correlation coefficient of "Guangluai No 4" was 4 = -0.6913*, i.e. when the number of effective panicles per mu increased by 10,000, the number of filled grains per panicle reduced by 0.8 grain.

Diagram 89 also shows that although a negative correlation exists between the number of effective panicles and the number of filled grains among the three varieties of early rice, the regressive coefficients do not differ markedly. This indicates that the effect of the number of effective panicles upon the number of filled grains possibly has nothing to do with the variety.





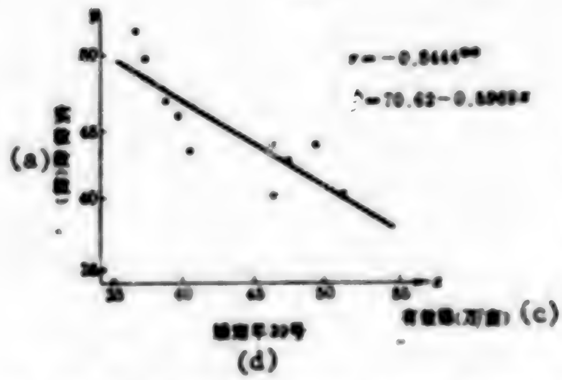


Diagram 89. Structural Relationship of Panicles and Grains of Rice*

Key:
(a) number of full grains (grain)
(b) Ainanzao No 1
(c) effective panicles (10,000/mu)
(d) Ainanzao No 39
(e) Guangluai No 4

* These diagrams were drawn from data compiled by the Shanghai Municipal Agricultural Science Academy, Crop Institute (1975). In the regressive function y = 72.36 - 0.1669x, y is the experience formula; 4 = -0.7624* represents the correlation coefficient, "-" is the negative sign. As r approaches -1.0, it indicates negative correlation, * indicates close correlation, ** indicates especially obvious correlation.

Under ordinary conditions, when the number of effective panicles increases by 10,000, the number of filled grains per panicle reduces by an average of 0.7 grain.

3. Equal Emphasis on Panicles and Grains

Production practices prove that when the development of the colony surpasses a certain level, the number of filled grains reduces even though the number of panicles still increases. A serious situation will lead to lodging, harm by insect pests and cause a decrease in production. Observations over the past several years in the Shanghai region of fields producing over 1000 jin per mu of paddy rice show when the number of panicles per mu surpasses 600,000, lodging occurs to varying degrees. The occurrence of lodging indicates that

the conflict between the individual plant and the colony has sharpened. It shows that further increases in the yield of paddy rice of the varieties presently being used cannot be realized simply through development of the colony (i.e., by increasing the number of panicles) but must also be realized through healthy development of the individual plants (increasing the number of filled grains per panicle). This means equal emphasis on both panicles and grains.

The Zhejiang Provincial Jiaxing Prefectural Agricultural Science Institute (1975) studied and analyzed the structure of panicles, grains and weight of grains of "Guangluai No 4" paddy rice variety in large fields producing over 1000 jin per mu. It was shown that the type of varieties with large panicles such as the "Guangluai No 4" can yield 1000 jin per mu when the number of effective panicles increases to about 400,000 and the 1000 grain weight reaches 26 grams and the number of filled grains per panicle reaches between 55 and 60 grains. Thus, under higher levels of paddy rice production techniques and with dual emphasis on production of grains and large panicles, i.e., by stabilizing the number of panicles for the production of large panicles in a colony producing 1000 jin per mu and by increasing the number of grains but not reducing the number of panicles, it is entirely possible to produce higher than high yields.

B. Physiological Basis for Increasing Production by Reasonably Dense Planting

Reasonably dense planting to increase production has a definite physiological basis. Li Xieping [2621 3610 1627] et al (1960) showed by systematic study that it is related to the characteristics of the colony of paddy rice noted below:

1. Reasonable leaf surface area coefficient and a high percentage of net photosynthetic production

Organic substances accumulated in the plant and produced by photosynthesis constitute 90 percent to 95 percent of the dry weight of the paddy rice plant. Green leaves are the organs of photosynthesis. Thus, development of the paddy rice colony within a definite range can increase the surface area of the leaves allow the plants to absorb more light energy and raise the percentage of utilization of light energy and the percentage of net photosynthetic production, thus reaching the goal of increasing the number of grains and the yield (Table 104).

Table 104 shows the leaf surface area coefficient increases as the planting density increases but the intensity of light and the percentage of net photosynthetic production decreases. Planting 320,000 basic seedlings will allow a rather reasonable structure in the colony (number of panicles) and produce a rather high percentage of photosynthetic products. Thus a high yield can be realized. When the number of basic seedlings surpasses 600,000, the structure of the colony will become overly developed and the intensity of light and percentage of net photosynthetic products will

Table 104. Amount of Yield by Pure Photosynthesis and Leaf Surface Area Coefficient Under Different Planting Densities

(a) 栽插密度 (万苗/亩)	(b) 平均叶面积系数	(c) 抽穗期(下午2时)光强		(f) 平均净光合生产率(克/米²/日)	(g) 每亩穗数 (万)	(h) 亩产 (斤)
		(d) 植株基部	(e) 株高2/3处			
16	6.38	200 米烛光 (i)	400 米烛光 (i)	2.62	30.24	839.21
32	7.27	90 米烛光 (i)	150 米烛光 (i)	2.70	37.78	900.65
48	7.86	70 米烛光 (i)	130 米烛光 (i)	2.81	48.48	852.63
64	9.55	60 米烛光 (i)	90 米烛光 (i)	2.22	60.30	817.81
80	10.80	60 米烛光 (i)	80 米烛光 (i)	2.05	73.60	795.84

Note: 1. Variety tested was "Guihuaqui." Fertilization level was heavy group fertilization.

2. In the table, data of the first three items were averages of the young panicle differentiation period, panicle bearing period, heading period and the end of milky ripe period.

Key:
(a) Planting density (10,000/mu)
(b) Average leaf surface area coefficient
(c) Heading time (2 P.M.) light intensity
(d) Base of plant
(e) At 2/3 of height of plant
(f) Average pure photosynthetic production (gram/meter²/day)
(g) number of panicles per mu (10,000)
(h) Yield per mu (jin)
(i) meter-candles

drastically be reduced, causing a reduction in yield. When the number of basic seedlings is below 160,000, the intensity of light incident upon the plants is high but because the number of panicles per mu is insufficient, the yield will not be high. The key to reasonably dense planting to increase the yield thus lies in a higher percentage of net photosynthetic products and the proper number of panicles.

2. More accumulation of dry substances and a higher coefficient of economic production

Because the net photosynthetic production percentage is higher under reasonably dense planting, more dry substances can be produced and more will accumulate. At the same time, these dry substances can be more easily transported to the grains and the development of the stem and leaves will be appropriate, the panicles will be large and the grains will be plentiful, thus producing a higher economic production coefficient and establishing a substantive material basis for high yields (Table 105).

3. Thick, strong stems resist lodging

The conflict between the colony and the individual plant under different planting densities is reflected in the changes in the characteristics of the stems and these changes vary widely. Variations due to these changes can directly affect the ability of the stem of the paddy rice plant to resist lodging (Table 106).

Table 105. Economic Yield Coefficient and Accumulation of Dry Subetances Under Different Planting Density

栽插密度 (万苗/亩) (a)	每穗实粒数 (b)	平均单株干物重 (克) (c)	(d) 生物产量 (斤/亩)			经济产量系数 (h)
			稻谷 (e)	茎叶 (f)	合计 (g)	
16	69.99	3.63	859.21	1186.9	2046.1	0.419
32	69.16	2.16	909.65	1345.0	2248.2	0.400
48	67.78	1.83	852.63	1470.0	2322.63	0.367
64	60.04	1.26	817.51	1515.0	2332.6	0.350
80	53.65	1.20	795.84	1478.5	2274.3	0.349

Note: Same as previous table

Key: (a) planting density (10,000 seedlings/mu)
(b) number of full grains per panicle
(c) average dry weight of single plant (gram)
(d) biological yield (jin/mu)
(e) grain
(f) leaf on stem
(g) total
(h) economic yield coefficient

Table 106. Resistance to Breaking and Lodging Under Different Transplanting Density

栽秧密度 (a) (万苗/亩)	(b) 茎秆单位长度干重(毫克/厘米)				(f) 抗折断力 (克)	
	抽穗期 (c)		乳熟末期 (e)		抽穗期 (c)	乳熟末期 (e)
	第一节 (d)	第二节 (g)	第一节 (d)	第二节 (g)		
16	21.3	14.1	12.8	10.7	807.13	443.60
32	14.4	10.4	12.7	7.4	492.50	303.50
48	12.5	10.4	11.0	6.8	301.30	282.77
64	10.9	6.6	10.4	6.6	250.63	182.00
80	7.7	6.2	9.6	6.3	184.10	130.50

Note: Resistance to breaking is measured as the number of grams which can be loaded onto the stem without breaking at 10 centimeters above ground. Explanation of the rest is the same as in Table 104.

Key: (a) transplanting density (10,000 seedlings/mu)
(b) dry weight of unit length of stem (milligram/centimeter)
(c) heading period
(d) first node
(e) latter part of milky ripe period
(f) resistance to breaking (gram)
(g) second node

Table 106 shows that under reasonably dense planting, the stems develop well, strongly and healthily (the dry weight of unit length is greater) and the resistance to breakage is stronger. This favors resistance to lodging.

In general, reasonably dense planting can increase production because of a proper structure of the colony. Under a proper structure of the colony, the leaf surface area coefficient is appropriate, the area of photosynthetic organs is large, the percentage of the net photosynthetic production is high, more dry substances can be accumulated, the economic production coefficient is high and the strength to resist lodging is strong, all of which benefit an increase in production.

C. Regulation of the Structure of the Paddy Rice Colony

Reasonably dense planting can increase production. This is recognized by all. But many factors affect the realization of increased yield because changes in the final yield and the factors of its formation are the indicators that reflect whether the planting density was reasonable. Viewed from the present situation, there are the following methods which can regulate the structure of the colony of paddy rice.

1. Regulation of the basic number of seedlings

In determining the density of planting of paddy rice plants according to the conditions of fertilization and irrigation in the paddy rice field, the first thing to do is to determine the number of basic seedlings. Under ordinary conditions, the size of the colony increases as the number of basic seedlings transplanted to each mu increases, thus affecting the panicles, the grains, the grain weight and the yield. Observations by the Hubei Xiaogan Prefectural Agricultural Science Institute (1974) of the effect of different numbers of basic seedlings upon the paddy rice colony and its yield are shown in Table 107.

Table 107 shows that the basic number of seedlings is an important factor affecting the size of the paddy rice colony. Especially in the middle and lower reaches of the Chang Jiang valley double cropped rice regions where the tillering period is short, the basic number of seedlings determines to a great extent the number of effective panicles regardless of the level of fertilization. Thus, assuring a certain basic number of seedlings for double cropped rice (especially late cropped rice) is a key measure in reasonably dense planting to increase production. Experiments show the most suitable number of basic seedlings per mu for early rice fields in the middle and lower reaches of the Chang Jiang region is between 250,000 and 300,000, and between 350,000 and 400,000 for late rice fields. Hybrid rice has a strong tillering ability and depends mainly on tillers to form panicles, thus only about 300,000 seedlings are needed.

Of course, the effect of the basic number of seedlings upon the development of the paddy rice colony is not absolute. The development of the paddy rice colony is also affected by fertilization and irrigation. A

Table 107. Effect of Different Base Numbers of Seedlings Upon the Paddy Rice Colony and Yield

(a)	(b)	(c)	(d)	(e)	(f)	(g)
低 (h) 肥	12.0	34.9	28.2	1.35	50.9	742.5
	18.0	40.1	31.2	0.73	48.4	803.5
	24.0	44.6	34.9	0.45	47.7	851.0
	29.4	56.2	37.1	0.28	45.3	838.0
	36.0	58.6	38.2	0.[illegible]	42.3	829.5
中 (i) 肥	12.0	37.9	31.2	1.60	52.6	866.5
	18.0	43.6	34.1	0.89	50.4	879.4
	24.0	46.2	36.3	0.81	49.1	914.0
	29.9	58.8	39.1	0.32	45.8	894.0
	36.0	64.6	40.5	0.12	38.0	798.9
高 (j) 肥	12.3	60.4	32.6	1.70	51.5	844.8
	18.0	68.9	35.6	0.99	49.9	872.0
	24.0	53.6	36.9	0.83	47.6	871.0
	25.8	67.3	38.5	0.35	44.9	853.0
	36.0	69.8	40.1	0.11	39.8	843.0

Note: Variety tested was "Xiaowan No 1" (late season rice). In the table, the number of effective tillers of the single plant is the number of effective tillers not including the main stem.

Key:
(a) level of fertilization
(b) Base number of seedlings (10,000/mu)
(c) Highest total number of tillers on stem (10,000/mu)
(d) effective panicles (10,000/mu)
(e) number of effective tillers per plant
(f) number of full grains per panicle
(g) yield (jin/mu)
(h) low
(i) medium
(j) high

survey conducted by the Zhejiang Ningbo Prefectural Agricultural Science Institute (1972) shows that as long as fertilization and irrigation management do not lag behind, stimulation and control of growth is appropriate. A higher total number of tillers can be produced even though the basic number of seedlings is few. Although the total number of tillers is small, enough effective panicles can be produced and higher yields can be realized (Table 108). Thus, after the basic number of seedlings has been determined, appropriate measures are still needed to stimulate or control the highest

total number of tillers so that there will not be too many nor too few tillers (The highest total number of tillers most suitable for double cropped rice generally is between 500,000 and 600,000). In fields where the basic number of seedlings is small, measures must be taken early to stimulate early and rapid tillering. In fields in which the total number of tillers is small, measures must be taken to increase the percentage of panicle formation to assure the necessary number of panicles for high yields.

Table 108. Relationship Between Base Number of Seedlings and Total Number of Tillers of the Main Stem and the Effective Panicles.

(a 基本苗 (万/亩)	(b 最高总茎蘖数 (万/亩)	(c 有效穗 (万/亩)	(d 成穗率 (%)	(e 产量 (斤/亩)
13.2	55.4	39.5	79.0	1061.6
19.0	44.6	38.9	87.2	1017.0
19.3	52.7	40.6	77.0	1001.8
21.8	50.0	34.4	68.8	1065.1
23.2	75.6	40.0	52.9	1012.1
26.1	57.0	38.9	68.0	1081.6
28.0	49.7	35.6	71.6	1009.8
28.9	67.8	42.2	62.2	1065.0

Key: (a) base number of seedlings (10,000/mu)
(b) highest total number of tillers on stem (10,000/mu)
(c) effective panicles (10,000/mu)
(d) percentage of panicle formation %
(e) yield (jin/mu)

2. Regulation of the number of seedlings per hole

The number of seedlings transplanted into a hole greatly affects the structure of the paddy rice colony. This is because the plants in the hole are comparable to the individual in the framework of the whole paddy rice field. As the single plant is related to the colony, so are the plants in the single hole related to the whole paddy rice field. So also the single seedling in the hole is related to the group of plants in the hole as the single plant is related to the colony. Thus, the conflict between the single plant and the colony also exists within each hole and to a very great extent this conflict is reflected in the competition for light and fertilizers. Therefore, when the number of holes in each mu is similar, the effect of increasing the number of seedlings in each hole in order to increase the number of panicles and the number of filled grains per mu varies as the number of seedlings in each hole varies. Observations by the Jiangsu Shuqian County Gangyao Brigade (1973) indicate when the number of holes in each mu is about 50,000

and the number of seedlings per hole is between 4 and 7, the effect of increasing the number of the basic number of seedlings is beneficial to the the production structure (indicator of reasonably dense planting). The yield pe mu can reach over 1000 jin. But when the number of seedlings in a hole is more than 8, the environmental condition for individual plant growth worsens and even though the number of basic seedlings and the number of effective panicles increase, the number of filled grains per panicle is adversely affected, thus causing a reduction in single crop production (Table 109).

Table 109. Effect of the Number of Seedlings per Hole on the Structure of the Panicles and Grains

a) 每亩穴数 (万)	b) 每穴苗数 (株)	c) 每亩基本苗 (万)	d) 每亩穗数 (万)	e) 每穗实粒数	f) 估产 (斤/亩)
4.93	4	19.72	22.82	91.6	1129
5.01	5	25.05	25.32	84.8	1162
5.02	6	30.12	28.11	68.6	1042
5.19	7	36.33	33.89	57.2	1017
5.03	8	40.24	34.52	53.7	945
5.24	9	47.16	39.12	41.5	828
5.00	10	50.00	40.15	35.9	735

Note: Variety tested was "Guihuahuang"

Key:
(a) number of holes per mu (10,000)
(b) number of seedlings per hole (plant)
(c) base number of seedlings per mu (10,000)
(d) number of panicles per mu (10,000)
(e) number of full grains per panicle
(f) estimated yield (jin/mu)

For double cropped rice in the Chang Jiang Valley, 5 to 7 plants per hole are appropriate for early rice and 6 to 8 plants per hole are appropriate for late rice.

3. Regulation of the distances between rows and between plants

The distances between plants and distances between rows are important links in the reasonable arrangement of the single plant's vegetative area and a reasonably dense planting to increase yield. They are also important aspects in full utilization of light energy and the soil's fertility for high yields. The broad poor and lower-middle peasants have made many innovations in this regard.

In general, the selection of the distances in dense planting is basically dependent upon the number of basic seedlings. When the basic number of seedlings is few and when the increase in the number of panicles depends

upon tillering, the distances between plants and distances between rows are often equal or close, for example, 4 x 4 cun or 4 x 3 cun so that the plants can receive light, temperature, water and fertilizers equally thus benefiting tillering. If the number of basic seedlings is large and panicle formation depends mainly on the main ste.., selection of dense planting distances generally should follow the nee. for aeration and light permeability during the latter growth period. Use wide distances between rows and short distances between plants, i.e., wide rows and narrow plantings such as 6 x 2 cun, 5 x 2.5 cun and 8 x 2.5 cun. Experiments show wide rows and narrow plantings as a method of dense planting is superior as manifested by the shape of the panicles and the weight of grains (Table 120).

Table 120* Effects of Wide Row Planting of Narrow Plants Upon the Characteristics of the Panicles and Grains of Paddy Rice (Guagdong Gaozhou County Scientific Technology Bureau, Zhongshan University Biology Department, 1976)

栽插规格(寸) (a)	基本苗数(万/亩) (b)	有效穗数(万/亩) (c)	穗长(厘米) (d)	每穗总粒数 (e)	每穗实粒数 (f)	结实率(%) (g)	千粒重(克) (h)	实际产量(斤/亩) (i)	前、中、后期施肥比例 (j)
8×2.5	26.1	25.86	21.4	125	86.8	82.7	24.65	966.7	5:4:1
5×4	24.3	28.02	20.8	98.1	78.8	80.3	24.50	912.2	5:4:1
5×4	26.4	23.64	18.1	81.1	67.2	82.8	23.96	862.0	6:2:2

Note: Variety tested was "Guangerai."

* [Note: Chinese text has misnumbered all tables following Table 109. Numbers 110-119 are omitted. The next table after 109 is 120].

Key:
(a) Transplanting specifications (cun)
(b) Base number of seedlings (10,000/mu)
(c) Number of effective panicles (10,000/mu)
(d) Length of panicle (centimeter)
(e) Total number of grains per panicle
(f) Number of full grains per panicle
(g) Fruiting percentage %
(h) 1000 grain weight (gram)
(i) actual yield (jin/mu)
(j) ratio of fertilization in the early, middle and latter growth periods

The major effect of wide rows and narrow plantings is to develop the superiority of the side rows by changing the structure of the colony in dense planting and improving aeration and light permeability. Since wide rows and narrow plantings retain the advantage of dense planting but also provide wider row distances, the leaves of the early and middle periods of growth of the seedling can grow erectly. The plants are shorter, the leaves at the lower portion of the plants are less shaded and since the efficiency of photosynthesis is high, more starch accumulates in the sheath of the stem, thus establishing a material basis for formation of large panicles, plenty of grains and weight of grains. During the latter growth period, a structure of the colony in which the top of the rows is closed but not the bottom

is favorable to increasing the ability to resist lodging. It is also favorable to lowering the temperature and humidity in the field, improving the microclimate in the field and suppressing the occurrence and development of diseases and insect pests. Therefore, the poor and lower-middle peasants believe a wide distance between rows and a narrow distance between plants are "a good method to combine sparsity and denseness where there is denseness in sparsity and sparsity in denseness." This can regulate the conflict between the colony and the individual plant well, solve the problems existing in reasonably dense planting and thus realize high yields.

4. Regulation of the direction of rows

Aeration and light permeability are not only related to the arrangement of the distances between plants and the distances between rows but also related to the direction of the rows. From the point of view of the direction of sunlight, an east-west direction allows the sun to shine upon the base of the paddy rice plants and between the rows. Therefore, early rice should be planted in rows in an east-west direction. As to aeration, the area south of the Chang Jiang region during the second half of the year has more southeasterly winds, thus rows in a north-south direction facilitate aeration and lowering of temperatures in the field which also benefit the plants.

In general, reasonably dense planting is established upon the basis of full utilization of the sun's light energy and raising of the intensity of photosynthesis to increase yield. It is related to the characteristics of the paddy rice variety, the intensity of light, supply of carbon dioxide and inorganic nutrients. In the cultivation of paddy rice, the structure of the colony is regulated by the number of basic seedlings, the number of seedlings per hole, the distance between plants and the distance between rows and their combinations and tillering and panicle formation so that a reasonable leaf surface area coefficient can be established and the number of panicles, the number of grains and the weight of grains in a unit area can be developed to their greatest extent for achieving high yields.

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CHAPTER 8. PHYSIOLOGICAL BASIS OF FERTILIZER APPLICATION

Fertilizers are food for plants and also the material bases for increasing paddy rice production. Fertilizer is the general term for all inorganic nutrients necessary for plants. Which inorganic elements are needed by paddy rice? How are these absorbed and utilized? How do we grasp the pattern of the need for fertilizers by the paddy rice plant and apply fertilizers reasonably? These are topics discussed in this chapter.

I. Inorganic Elements Needed by Paddy Rice and Their Physiological Functions

The paddy rice plant, like other crops, generally contains 70 percent to 75 percent water and 25 percent to 30 percent dry substances. The dry substances consist of carbon, oxygen and hydrogen from carbon dioxide and water as well as nitrogen, phosphorus, potassium, silicon, calcium, magnesium, sulphur, iron and zinc from the soil.

Analysis of the major inorganic elements needed by paddy rice throughout its life shows that the paddy rice plant contains a lot of nitrogen, phosphorus, potassium and silicon and lesser amounts of magnesium, calcium and sulphur and minute amounts of iron and manganese. Hagiwara (1958) showed by analysis the changes in the content of inorganic elements in the paddy rice throughout the process of development as listed in Table 121. In general, the elements that are high in content in the body of the paddy rice plant and that are naturally deficient in the soil are those which affect the growth and development and the yield the most.

The physiological function of the elements necessary to the paddy rice plant are described below:

A. Nitrogen

All cultivated paddy rice requires nitrogen fertilizers and no other nutritive element has more effect upon the yield of paddy rice than nitrogen.

Nitrogen is the major content of protein--the plant's cytoplasm. It is also a component in the formation of the plant body and especially in the formation of leaves and stems. The massive application of nitrogenous fertilizers during the tillering period of paddy rice is related to the massive increase in growth of the stems and leaves.

Table 121. Changes in the Content of Inorganic Substances During the Growth Process of Paddy Rice (Unit: milligram/plant)

(a) 测定日期 (月 日)	(b) 氮 (N)	(c) 磷 (P_2O_5)	(d) 钾 (K_2O)	(e) 钙 (CaO)	(f) 镁 (MgO)	(g) 锰 (Mn_2O_3)	(h) 硅 (SiO_2)
7/3 (i) (移栽期)	2.6	1.7	2.8	0.4	0.5	0.1	6
7/20 (j) (分蘖期)	42.7	19.1	63.4	8.3	6.7	0.6	19
8/3 (分蘖盛期) (k)	321.9	85.9	268.9	40.7	36.1	2.1	983
8/24 (幼穗分化期) (l)	425.4	160.4	429.5	88.5	65.8	4.4	2264
9/13 (m) (抽穗期)	686.8	210.5	429.8	152.1	119.3	22.6	6314
10/10 (n) (乳熟期)	702.1	233.3	574.5	139.5	97.5	41.9	7120
11/7 (o) (完熟期)	853.9	263.5	754.0	174.8	112.4	36.9	8378

Key:
(a) Date of measurement
(b) nitrogen
(c) phosphorus
(d) potassium
(e) calcium
(f) magnesium
(g) manganese
(h) silicon
(i) 7/2 Transplanting stage
(j) 7/20 Tillering stage
(k) 8/3 Peak tillering stage
(l) 8/24 Young panicle differentiation stage
(m) 9/13 heading stage
(n) 10/10 milky ripe stage
(o) 11/7 completely ripe stage

Nitrogen in the paddy rice field is absorbed by the paddy rice roots mainly in the form of ammonium ions. The ammonium absorbed by the roots combines with the organic acid α-ketoglutaric acid of the respiratory pathway to form an amino acid called glutamic acid:

$$\text{Ammonia} + \alpha\text{-ketoglutaric acid} \longrightarrow \text{glutamic acid.}$$

After synthesis of glutamic acid, the plant produces other amino acids from organic acids by the action of amino mutase. For example:

$$\text{Glutamic acid} + \text{pyruvic acid} \rightleftharpoons \text{alanine} + \alpha\text{-ketoglutaric acid}$$

$$\text{Glutamic acid} + \text{oxalic acid} \rightleftharpoons \text{aspartic acid} + \alpha\text{-ketoglutaric acid}$$

The ammonia absorbed by the roots is synthesized into amino acids in the root and is generally transported to the leaves in that state. When a supply of energy exists (as ATP (adenosine triphosphate), a form of photosynthetic product (sugar) released in respiratory metabolism), amino acids are synthesized to form protein.

Nitrogen is also a major content of chlorophyll. After application of nitrogenous fertilizers, the green color of the leaves of paddy rice darkens and the speed of photosynthesis hastens. This is the cause of the increase in the content of chlorophyll.

When there is a deficiency of nitrogen, the synthesis of protein and chlorophyll is hindered, the plant becomes small and short, the leaves become small and yellow, tillering is less and the rice panicles are short and small. In addition, the deficiency of nitrogen causes the nitrogen in the leaves to be transported to the new organs earlier. The plant shows signs of early withering and the function of the leaves reduces and weaken. The leaves die. Such occurrences during the latter period in particular often seriously affect the yield of paddy rice.

But, too much nitrogen is also unfavorable to the normal growth of paddy rice. Too much nitrogen causes the leaves to droop and to grow overly long, large and loose, increases ineffective tillers and causes the plant to lodge easily. The plant easily becomes diseased and damaged by insects. This is because the plant has absorbed too much nitrogen and too much protein has been synthesized. The amount of ammoniacal nitrogen and soluble nitrogen increases, the resistance of the plant to bacteria is lowered, and in particular, the plant easily becomes affected by blast of rice and rice borers.

It should be pointed out that of the nitrogen absorbed by the paddy rice plant, only one-third comes from chemical fertilizers. The remaining two thirds come from the soil. In particular, surplus-yielding paddy rice absorbs most of its massive amounts of nitrogen needed from the soil (Table 122), that is, relying on decomposition of the soil's organic substances (humus) to produce ammonia. Nitrogen originating from the soil is distributed throughout the entire plowing layer and is gradually absorbed by the roots as they grow. Over absorption will not occur at any particular time and the paddy rice plant can safely absorb large amounts of nitrogen. Thus, application of organic fertilizers and deepening the plowing layer to increase the supply of nitrogen in the soil are important to cultivation of high-yielding paddy rice.

Table 122. Sources of Nitrogen in the Paddy Rice Plant (%)

	N^{15}--ammonium hydrocarbonate (sidedressing)	Soil
Early rice (variety: "Zhongganzao")	36.6	63.3
Late season rice (variety "Jianong No 14")	15.6	84.4

B. Phosphorus

Phosphorus is the major content of nucleic acid. The nucleus that undergoes cell division particularly contains more phosphorus. Thus, during cell reproduction in the tillering period, phosphorus is necessary for increasing the amount of tillering. Sometimes stunting that occurs in the paddy rice plant is related to a deficiency of phosphorus. At the same time phosphorus is the component of ATP (adenosine triphosphate) and ADP (adenosine diphosphate) which affect conversion and storage of energy in an important way. In addition, phosphorus plays an important role in the synthesis of starch and cellulose. After heading, phosphorus is transported from the leaves of the stem to the panicles and participates in the synthesis of starch in the rice grain. Phosphorus is the easiest element to transport within the paddy rice plant and the element which is most easily reused.

Deficiency of phosphorus is manifested by overly long and thin leaves and dark green color. A serious deficiency is manifested by reddish brown colored spots. The roots are poorly developed, tillering occurs less and the growth period is delayed. Early rice absorbs phosphorus poorly because of low temperatures, thus increased application of phosphorus fertilizers in the seedbed can stimulate the plants to grow well after transplanting. Phosphorus also functions to stimulate the absorption of nitrogen. Application of phosphorus and nitrogen at the same time during the tillering period will prevent the seedlings from stunting but a two-generous application of nitrogen and phosphorus will easily render the plant suspectible to blast of rice. Conversely, a deficiency of phosphorus will reduce the function of respiration and photosynthesis and weaken the synthesis of protein, thus making plant easily susceptible to blast of rice.

C. Potassium

Potassium is different from phosphorus and nitrogen. It does not participate in the composition of important organic matter in the paddy rice plant. It exists as an inorganic salt, i.e., in an ionic state or as free ions or is unstably adsorbed by colloidal bodies. However, it is still an element needed in great amounts by the paddy rice plant and serves an important function in the physiological activity of the paddy rice plant.

The tender parts of the paddy rice plant and the parts of active growth, especially the buds, young leaves, tips of roots all contain large amounts of ptassium. The ashy parts of these parts can contain as much as 50 percent potassium. This is related to the participation of potassium in the synthesis of protein and the structure of protoplasm. Deficiency of potassium can lessen the nitrogen content of protein, increase the content of amino nitrogen and nitrogen amides and destroy protoplasm. Thus, when increasing the level of fertilization of nitrogen fertilizers, the amount of potassium fertilizers should also be increased so that the ratio of potassium to nitrogen (K_2O/N) will be small.

Potassium is closely related to the synthesis and transportation of carbohydrates in the rice plant and especially closely related to the synthesis of such polysaccarides as starch, cellulose and lignin. Sufficient supply of potassium benefits filling of the seed grains fully and the development of the mechanical tissues so that the stems will be strong and resilient and will have a strong resistance to lodging.

Recent studies support the belief that potassium is related to the opening of stomates.

When the paddy rice plant is deficient in potassium the leaves are dark green, the plant is short, brown spots and abnormal wrinkles appear on the blades of the leaves, the rim of the apex of leaves curls up, and the leaves finally wilt. Deficiency of potassium is manifested first by leaves on the lower part of the plant and then the [illegible] progress to the upper leaves because potassium often is transpor[illegible] the differential tissues of the meristems. After a deficiency of pot[illegible] occurs in a paddy rice plant, the plant becomes weakly resistant to white leaf blight and Huma (5170 7802) leaf spot disease. The stems become soft, and weak and easily lodge.

Reduction in the yield of paddy rice caused by a lack of potassium is manifested most clearly during the most prosperous tillering period and formation of young panicles when the content of nitrogen is the highest. Deficiency of potassium during the prosperous tillering period when the potassium and nitrogen ratio is below 0.5 causes reddish brown spots to appear on the leaves at the lower part of the plant because the potassium in the leaves has been transported to the upper leaves and the lower leaves wilt. Deficiency of potassium during the period of formation of young panicles causes the number of spikelets on each panicle to reduce and thus causes a reduction in yield.

D. Silicon

Paddy rice is a representative silicate. It absorbs large amounts of silicon and the content of silicon in the stems and leaves can reach a dry weight of 10 percent to 20 percent. High-yielding paddy rice contains especially high contents of silicon. After silicon is absorbed by the roots it rises along with the water inside the body of the plant because of transpiration. Water transpires from the leaves and most of the silicon is accumulated on the surface of the epidermal cells. Because of this accumulation of a layer of hard silicon on the surface of the epidermal cells of the leaves and stem, the resistance against disease and insect pests of paddy rice is strengthened and transpiration from the surface of the leaves is reduced. At the same time the plant becomes resistant to lodging.

The physiological function of silicon is to stimulate the roots' oxidation ability so that absorption of other nutrients by the roots is stimulated.

When there is a deficiency of silicon (when the content of silicic acid is lower than 10 percent, the amount of extract of silicate from the soil's acetic acid solution is less than 10.5 milligrams/100 gram/hour) and the amount of silicon accumulated on the surface of the epidermal cells of paddy rice reduces. Thus, the pathogens of blast of rice and Huma leaf spot easily enter the plant through the epidermis. When silicification of the epidermal cells of the grain is poor and the grain is affected by the above diseases, brown spots emerge on the surface and infect the panicles.

Present studies indicate silicon and nitrogen seem to have opposite functions. Plants with a high ratio of silicon and nitrogen grow healthily. If there is too much nitrogen, the ratio of silicon and nitrogen lessens. Thus, the effect of silicon is clearly visible when too much nitrogen is applied. Weeds, compost of rice stems and wood ash contain a lot of silicon fertilizers. Raising the content of silicon in the rice field is significant to cultivating high-yielding paddy rice.

E. Magnesium, Calcium, Sulphur

Magnesium, calcium and sulphur are components of some parts of the paddy rice plant. For example, magnesium is a component of chlorophyll, sulphur is a component of some amino acids and calcium is a component of some enzymes. Thus, they are needed in the normal metabolism of paddy rice. Although these elements exist in lesser amounts in the paddy rice plant, generally the content in the soil is sufficient for the need of the paddy rice plant. Except for extraordinary conditions, these elements are not applied as fertilizers.

F. Iron, Manganese, Boron, Zinc, Molybdenum, Copper

Although the absolute amount of these elements needed by the paddy rice plant is very small (called microelements), they have important functions in metabolism, emergence of organs, synthesis and transportation of substances in the paddy rice plant. For example, iron and manganese participate in the formation of chlorophyll, boron participates in the formation of pollen and fertilization and zinc is realized to the formation of chlorophyll and auxins.

The above analysis shows that paddy rice not only needs nitrogen, phosphorus and potassium but also needs other inorganic elements, especially when the level of nitrogen fertilization is high and the yield is high. Silicon and zinc seem to have a visible effect upon increasing production. Their reasonable application may become a new path towards producing higher yields from high yields of paddy rice.

II. The Root System of Paddy Rice

The inorganic elements and their physiological functions needed by paddy rice have been described above. These elements that are in the soil have

to be absorbed by the roots. Although some soils have a rich potential source of nutrients, various reasons will cause the root system to grow poorly and weaken the ability of absorption. Thus the paddy rice plant will not grow well and the yield will not be high. Therefore, the condition of the root system is significant to the absorption of inorganic nutrients.

a. Anatomic Characteristics of the Root System of Paddy Rice

The root of paddy rice is a fibrous root. At germination, a seed root emerges as the first root. Other roots that follow are called crown roots. Crown roots can be further divided according to shape into ordinary roots and free roots. Crown roots emerge from the nodes underground. A few crown roots grow from the lower nodes and as many as several dozens of crown roots can emerge from the higher nodes. The angle at which roots grow from the main stem are wider at the upper nodes. Roots may even grow horizontally. The roots branch out prosperously like a net [fibrous root system]. These roots are generally called free roots. Free roots are physiologically active, can absorb oxygen and can transport oxygen to the lower root system of the paddy rice plant. This is an important function for the growth and development of paddy rice during the latter period.

After the root emerges, it branches out into branch roots or side roots. These roots emerge from the stele sheath of the root. There are two kinds of branch roots; the large branch roots and the small branch roots that emerge from the large branch roots.

The roots of paddy rice (including branch roots) have root hairs at the tender parts. Root hairs grow from specialized epidermal cells as a hair-like structure.

Meristems exist at the tip of the paddy rice roots and are covered by the root cap (Diagram 90). The differentiating tissue of meristems continues to divide so that the root continues to grow. The tip of the root and the root hair (behind the growth zones of the root) are the major parts of the root that absorb nutrients and moisture. The emergence of root hairs and branch roots greatly increases the area of absorption of the roots of the paddy rice plant. The Botany Teaching and Research Group of the Biology Department of the former East China Teacher's University (1962) showed in its study that the total lengths of the branch roots with diameter less than 0.2 millimeters can reach 252.7 to 1181.4 meters long and the roots can span 0.15 to 0.71 square meters.

The structure of the root of paddy rice is similar to that of other crops. It can be divided into the epidermis, the cortex and the stele (Diagram 91).

The epidermis is the outermost layer of cells of the paddy rice root. The cells have a short life and after the root hairs wither and die the epidermal cells often decompose and shed.

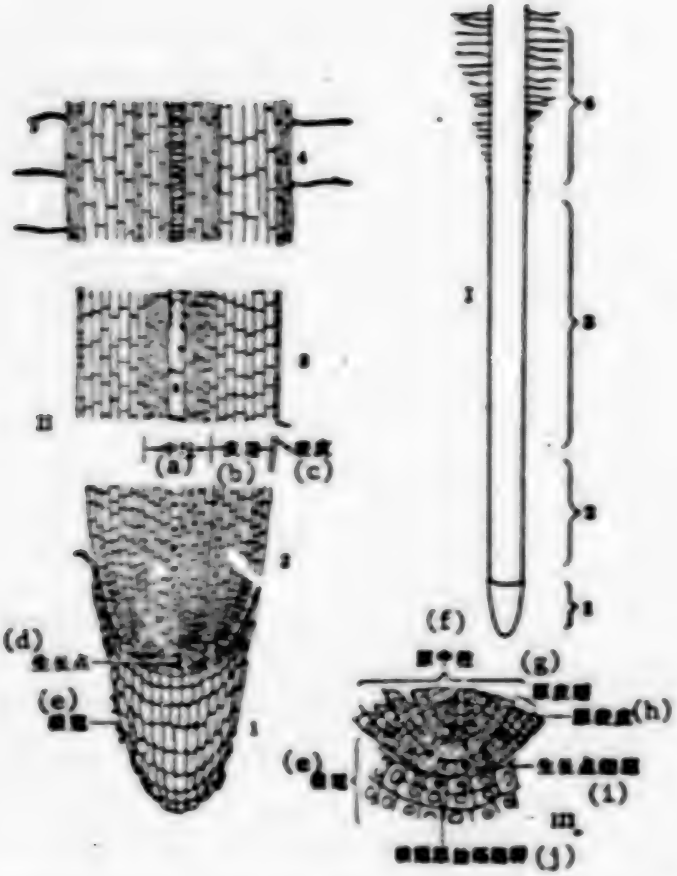

Diagram 90. Longitudinal Section of the Paddy Rice Root (Hoshigawa Kiyoshin, 1975)

I. Outer shape of a root

II. Longitudinal section of the seed root: 1. Root cap, 2. Cell division zone, 3. Elongation zone; 4. Root hair zone.

III. Enlargement of II (1,2)

Key:
(a) stele
(b) cortex
(c) epidermis
(d) meristem
(e) root cap
(f) primordial stele
(g) primordial cortex
(h) primordial epidermis
(i) meristem cells
(j) primordial cell group of root cap

The epidermis of the root of paddy rice is a part with a special structure. On the outer side of the epidermis of the paddy rice root is a layer of visible thick walled cells. The epidermis of old roots have air sacs that

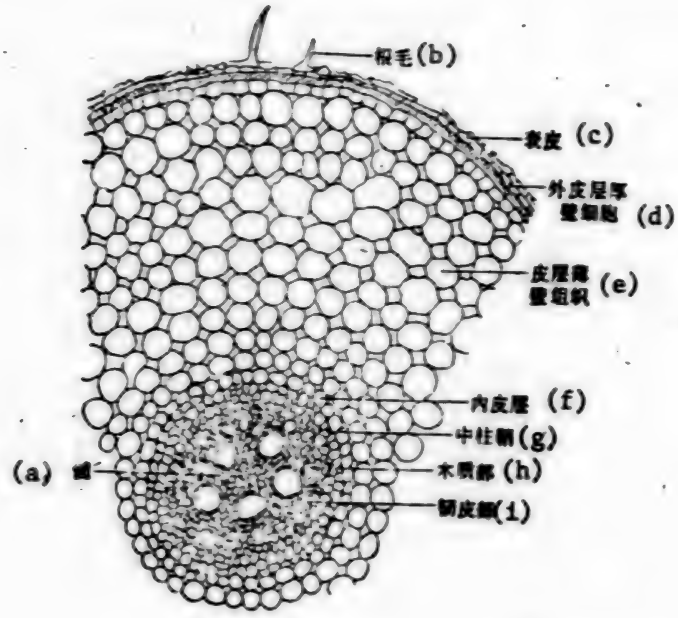

Diagram 91. Cross section of a part of the young root of paddy rice

Key: (a) vascular cambium
(b) root hair
(c) epidermis
(d) exodermis thick walled cells
(e) parenchyma of the cortex
(f) endodermis
(g) stele sheath
(h) xylem
(i) phloem

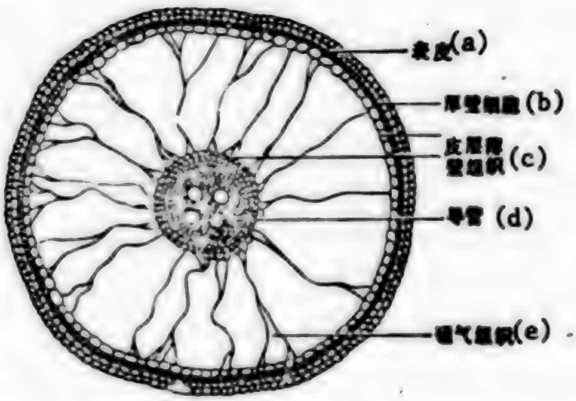

Diagram 92. Structure of an Old Root of Paddy Rice (cross section)

Key: (a) epidermis
(b) thick walled cells
(c) parenchyma of cortex
(d) duct
(e) aerate tissue

are adaptive to the underwater ecology. Air sacs are separated by several layers of parenchyma cells and disperse to become channels. These air sacs are separated by thin plates formed by decomposed epidermal parenchyma cells and remnant cell walls (Diagram 92). The air channels are connected with air pockets of the leaves and the stems forming a good ventilation system. Oxygen entering through the stomates and the oxygen produced by photosynthesis can reach the roots via these air sacs to supply the needs of the root during respiration. Air sacs enable the plant to adopt to submerged conditions. Seedlings prior to the third leaf stage do not have a well developed system for aeration and the needed oxygen has to be obtained from the soil. Thus field management should emphasize cultivation in wet fields as the main method of cultivation.

The stele is the transporting tissue. The stele is formed by the protostele or the stele primordium belonging to the part inside the endodermis. The outermost layer of the stele is the stele sheath composed of parenchyma cells. Branch roots emerge from the stele sheath cells after they actively divide. The stele sheath envelops the major part of the stele including several bundles of xylem. The xylem of each bundle is composed of several tracheids which transport moisture and inorganic salts. The phleom is inside the xylem. Each bundle of phloem is composed of several tracheae and companion cells. The tracheae transport nutrients. The stele of the old paddy rice root, except for the phloem, has all lingnified and thickened, thus the stele not only has the capability of conduction but also serves as a strong support.

B. Growth of the Root System of Paddy Rice

Except for the seed roots that emerge during germination, all roots emerge from the nodes on the stem (Table 123) and in a definite relationship to the emergence and development of leaves. In general, when leaf n emerges, the root on the n - 3 node on the same stem emerges at the same time (See Chapter III Diagram 26). Thus, the nodes from which roots have emerged can be determined by observing the leaf ages of the leaves on the part of the plant above ground. By the pattern of the number of roots that emerge on different nodes, the rooting situation of the root system can be determined and necessary cultivational measures can be taken.

Table 123. Number of Roots on Different Nodes of the Main Stem

(a) 主茎节位	0	C_1	C_2	1	2	3	4	5	6	7	8	9	10	11	12
(b) 根数	1	6.3	6.3	8	10.1	11.8	13.8	14.9	20.8	21.6	22	21.3	23.3	22.6	18.4

Note: 0: seed roots. C_1: plumule sheath leaf nodes. C_2: incomplete leaf node

Key: (a) Node position on the main stem
(b) Number of roots

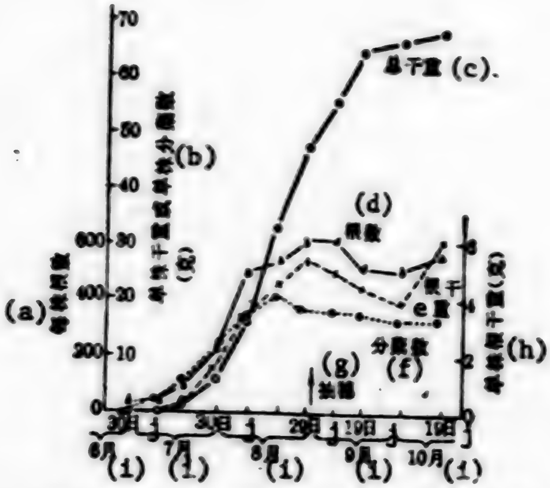

Diagram 93. Relationship Between Tillering and Growth of the Paddy Rice Roots (Inada, 1967)

Key:
(a) Number of roots per plant
(b) Dry weight of single plant or number of tillers of single plant (gram)
(c) Total dry weight
(d) number of roots
(e) dry weight of roots
(f) number of tillers
(g) heading
(h) dry weight of roots of single plant (gram)
(i) month
(j) day

The growth of roots is manifested by increases in number and weight. Table 93 shows that the increases in the number of roots and the weight of roots are proportional to the increase in the number of tillers which reaches a peak during the heading and flowering periods. Thus, it is important to stimulate early and rapid emergence and growth of the tillers and the root system of double cropped rice.

From the seedling period to the tillering period, the paddy rice roots grow horizontally within a depth of 20 centimeters in shallow soil and are distributed in a flat oval shape. From the end of tillering to the period of jointing, the roots rapidly grow downward and reach their maximum length at the time of heading. Their distribution is in the shape of an inverted egg. The Nanjing Pedology Institute of the Chinese Academy of Sciences (1975) injected rubidium isotope Rh^{86} into the roots and determined that 2 months after transplanting of paddy rice, 85 percent of the root system are distributed within the soil layer between 0 and 16 centimeters deep (Table 124).

The most suitable temperature for growth of the root system of paddy rice is between 30°C and 32°C. A ground temperature of below 15°C is unfavorable to the growth and development of the root system and when the temperature is below 9°C to 10°C, the growth of the root system ceases.

When the soil's aeration is good and the rooting strength is strong, the roots will develop longitudinally. When the paddy rice field is constantly submerged, the roots of the paddy ice plant will not branch out and the roots extend mostly horizontally which is unfavorable to proper growth of the paddy rice root.

When the mature soil layer in the paddy rice field is thick and fertilizers are sufficient, especially when there is a rich source of nitrogenous fertilizers, the rooting strength is strong. Studies indicate that the emergence and growth of the roots of paddy rice are related closely to the nitrogen content in the stems. When the content of nitrogen in the stems is above 1 percent, the roots will grow. When the content of nitrogen at the base of the stem is 1 percent, new roots will cease to emerge and existing roots will not elongate too much. When the nitrogen content falls to 0.75 percent, emergence of new roots and elongation of old roots cease. Deep application of fertilizers can stimulate roots to grow deeply (tropism towards fertilizers).

Our experiments conducted in 1974 showed spraying of nucleic reducing solvent ("702") 1 to 3 days prior to uprooting the seedlings strengthened the seedling transplanted by hand or by machine to root and absorb fertilizers (Diagram 94), thus facilitating early greening and early tillering. Experiments in the large fields also showed uniform results (Table 125).

Table 124. Distribution of Paddy Rice Roots in the Field

土壤层次 (厘米) (a)	(b) 射线计数 (脉冲/分)						相对根量 c) (%)
	1	2	3	4	5	6	
0~8	262	508	636	291	332	876	72.8±4.7
8~16	34	71	139	48	74	104	12.8±3.4
16~24	23	48	51	43	46	64	7.6±1.7
24~32	[illegible]	30	46	39	44	48	6.6±2.1

Key: (a) soil layers (centimeters) (b) radiation count (pulse/minute) (c) amount of corresponding roots (%)

C. Function of the Root System of Paddy Rice

More profound studies have enabled people to gain a deeper understanding of the function of the paddy rice root system. It not only has the ability of absorption but also the ability to store nutrients and engage in synthesis. It not only functions like the root system of other crops but also has the ability to adapt to submerged conditions and secrete oxygen. In addition, it also possesses the function of fixing carbon dioxide in the soil and maintaining the level of protein of the paddy rice plant. These functions are briefly described below.

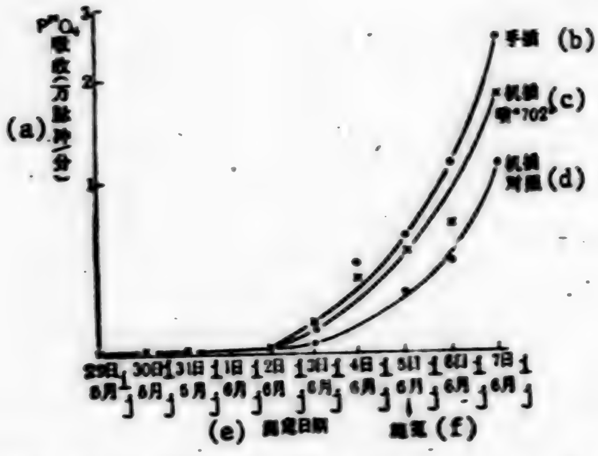

Diagram 94. Effect of Spraying "702" (40 ppm) upon the Absorptive Capability of Paddy Rice after Transplanting by Machine Before Uprooting of the Seedling.

Key: (a) $P^{32}O_4$ absorption (10,000 pulse/minute)
(b) transplanted by hand
(c) transplanted by machine and sprayed with "702"
(d) machine transplanted control
(e) dates of measurement
(f) nitrogen applied
(g) day
(h) month

1. Absorption of moisture and nutrients

Everyone knows that the most obvious function of the root of the paddy rice plant is the absorption of moisture and nutrients. Since the differential meristems of the paddy rice root have not differentiated into ducts, regardless of what quantity of nutrients are accumulated at the meristem region of the root, these nutrients cannot be transported upward. In the root hair zone where ducts have differentiated, the root has the ability to transport the nutrients and has a large absorptive surface. Thus, the root hair zone is the most active zone for absorption of nutrients and moisture.

How does the root absorb moisture and nutrients? The actual mechanics of the absorption of nutrients by the root system has yet to be clearly understood. Studies indicate absorption of nutrients and moisture can be divided into passive absorption and active absorption. Passive absorption refers to the absorption of inorganic ions by the root system due to differences in osmotic pressure in the root system and the environment or by the physical and chemical process of exchange and absorption. Active absorption is a process that consumes energy and is closely related to the physiological process of respiration within the body of the plant. These two processes may exist simultaneously in the absorption of nutrients. The absorption of nutrients requires expending of energy and thus is closely related to respiration.

Table 125. Effect of Spraying "702" Upon Vitality and Growth of Early Rice's Root System Transplanted by Machine Before Uprooting of Seedlings

Treatment	Average number of roots of single plant	Average length of roots (cm)	Number of Potential roots of single plant	Intensity of respiration of root system (O_2 microliter/hour/gram fresh weight)
Transplanted by hand	10.30	5.50	0.03	692.4
Machine transplanted and sprayed with "702"	11.50	5.20	0.77	963.2
Machine transplanted without spraying "702"	9.03	4.53	0.03	824.0

Note: (1) Variety tested was "Fuzao No 2" sprayed with 40 ppm of "702" 2 days before uprooting and transplanted on 27 May, measured on 2 June.

(2) Intensity of respiration of roots was measured in the greenhouse using a respiration density bottle.

Experiments by Tanaka (1960) showed if the paddy rice seed was allowed to germinate and grow in the dark, the content of starch within the seed will have been completely exhausted by the three leaves stage. The experiment involved cutting the tip of the second leaf and injecting different concentrations of glucose (so that the plant absorbed glucose for 3 days) and then supplying the root with P^{32}. Measurements of the P^{32} pulse after 4 hours were taken as listed in Table 126.

Table 126. Relationship Between the Amount of Absorption of P^{32} and the Supply of Sugar

Concentration of sugar solution (%)	0	1	2.5	5
Absorption of P^{32} (pulse/2 plants)	858	2009	2659	4490

Table 126 shows that the higher the concentration of sugar (the basic material for respiration), the more phosphorus is absorbed. This is because the germinating seedling in the dark has basically exhausted its basic material for respiration (sugar) at the third leaf stage. Respiration of the root is weak and thus the absorption of phosphorus is also weak.

When sugar is supplied, the plant receives the basic material for respiration, thus respiration of the roots intensifies and the absorption of phosphorus is stimulated.

The close relationship between the absorption of the root system and the intensity of respiration can be seen from the experiments conducted by Papa (Japanese) (1958). It was shown that the amount of absorption of nitrogen of a part of the root was proportional to the intensity of respiration of that same part of the root (Table 127).

Table 127. Amount of Absorption of Nitrogen and Intensity of Respiration of Different Parts of the Paddy Rice Roots

Part	Intensity of respiration (O_2 microliter/gram fresh weight/hour)	Absorption of nitrogen (microgram/gram fresh weight/hour)
Base	161	7.8
Middle	350	13.2
Tip	423	17.4

2. Secretion of oxygen of the root system

Although the root system of the paddy rice plant is submerged in water in the plowing layer that is strongly reducing, it is not harmed by the reducing substances mainly because of its glycolic acid cycle. Via this cycle and under the function of hydrogen perioxidase, the oxygen transported through the leaves and stems down to the roots (studies indicate the amount of oxygen transported from the stem and leaves to the roots can amount to 50 percent of the total amount of oxygen absorbed by the stems and leaves) is converted into hydrogen peroxide. Hydrogen peroxide, under the action of hydrogen peroxidase, becomes a strongly oxidizing new active oxygen which is released around the roots. It forms an oxidizing circle which reduces damage to the roots by the reducing substances and maintains the physiological functions of a prosperous root system (Diagram 95).

The major characteristic of the glycolic acid cycle is the existence of glycolic acid oxidase which has been proven to exist actively in the root of the paddy rice plant. Some have determined that the activity of glycolic acid oxidase at the tip of the root within 0 to 3 centimeters amounts to 20.2 milliliter oxygen/hour/milligram equivalent enzymic fluid. This coincides with the fact that the tip of the root has the strongest oxidizing capability. We generally determine the oxidation of α-naphthylamine by measuring the oxidation of α-naphthylamine by H_2O_2 produced in the glycolic acid pathway (see Experiment 7 in Appendix). The Zhejiang Agricultural

Key:
(a) glucose
(b) pyruvic acid
(c) Acetyl-CoA
(d) acetic acid
(e) glycolic acid
(f) glycolic acid oxidase
(g) aldehyde acid
(h) superhydroxide enzyme
(i) xanthine oxidase
(j) new active oxygen
(k) oxalic acid
(l) oxalic acid decarboxylating enzyme
(m) oxalic acid oxidase
(n) formic acid
(o) hydrofolic acid
(p) methyl-4-hydrofolic acid

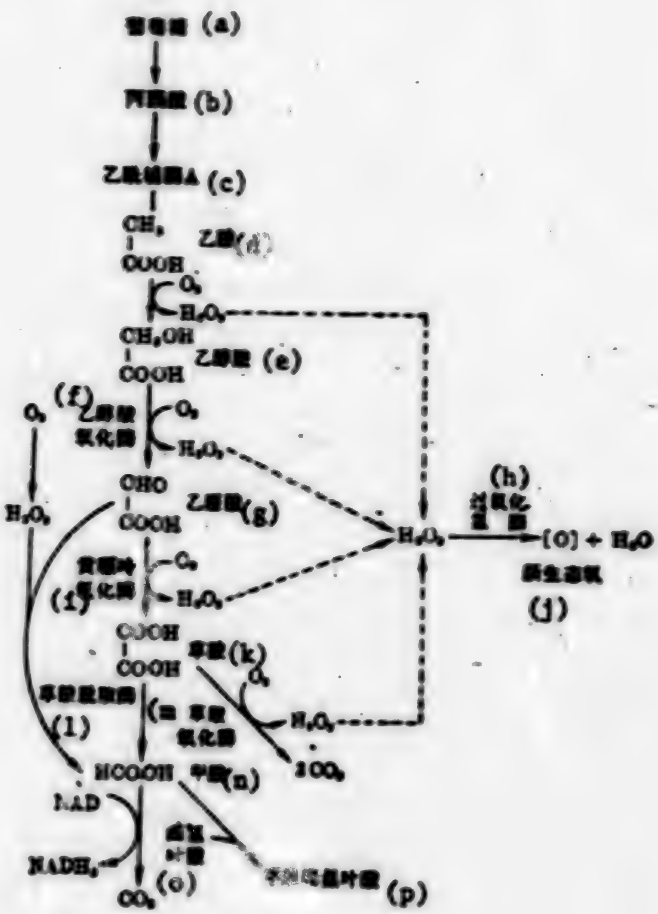

Diagram 95. The Glycolic Acid Pathway in the Paddy Rice Root

University and the Zhejiang Academy of Agricultural Sciences, Crop Institute determined that the strength of oxidation of α-naphthylamine of late geng "Jianong No 15" was the strongest during the transplanting stage (158 micrograms/hour/gram fresh root), followed by the young panicle differentiation stage (147, same unit) followed by the tillering stage (115), and the lowest during the heading period (124). This reflects the changes in activity of the root system during the entire life of paddy rice.

The color of the root system of the paddy rice plant is related to the ability of the root system to secrete oxygen. New roots of paddy rice have a strong ability to secrete oxygen. It can oxidize ferrous oxide within several millimeters around the roots into water and a ferric oxide compound which settles around the roots, thus allowing the roots to remain white or retain its original color. As the paddy rice root ages its ability to

secrete oxygen weakens or an increase in the amount of reducing substances in the soil shrinks the area of oxidation by the roots down to the surface of the roots, allowing the water and ferric oxide resulting from the oxidation of ferrous oxide to deposit on the surface of the roots. The root thus takes up a thin reddish brown colored ferrous membrane commonly called "yellow roots." If the root's ability of oxidation further weakens or the reducing state of the soil further increases and when such substances as hydrogen sulphide are produced, the ferrous oxide in the soil combines with the hydrogen sulphide to form a poisonless black ferric sulphide which adheres to the surface of the root, making the roots black. The physiological function of these black roots is very weak. If the roots are further damaged by hydrogen sulphide, they will rot or become light gray in color. The poor and lower-middle peasants often say "white roots have strength, yellow roots keep living and black roots give away their life." This vividly describes the relationship between the changes in function of the root system and the color of the roots.

3. Fixation of carbon dioxide

The amount of inorganic carbon in the soil amounts to 0.5 percent to 1.5 percent of the amount contained in the air in the soil, 50 times greater than the amount of carbon in the air by volume which is between 0.03 percent and 0.035 percent. At the same time, the solutions in the soil also contain dissolved carbon dioxide. Related experiments prove that like other crops, paddy rice's root system can also fix the carbon dioxide in the soil and transport it to the parts of the plant above ground as raw material for photosynthesis (Diagram 96). Studies indicate the amount of carbon dioxide originating from the soil and entering the seeds amounts to about 2 percent of the total amount of carbon absorbed.

Key:
(a) part above ground
(b) underground part
(c) sugar
(d) photosynthesis
(e) malic acid
(f) oxaloacetic acid
(g) (pyruvic acid)
(h) (tagged soil carbon dioxide)

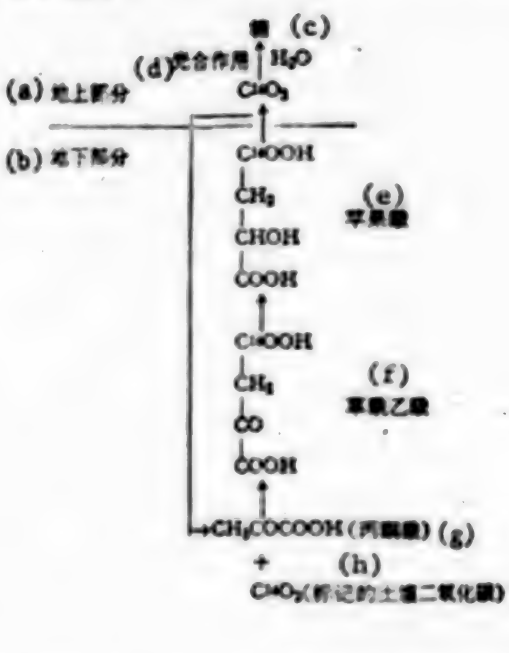

Diagram 96. Pathway of Carbon Dioxide Fixation in the Root System

The difference between paddy rice and other crops is that the chemical compounds of fixed carbon dioxide being transported upwards include not only malic acid but also citric acid, glutamic acid and aspartic acid. Of these citric acid accounts for the largest amount.

4. Maintaining the level of protein in the paddy rice plant

It has been mentioned previously that the ammonium absorbed by the root of the paddy rice plant combines with α-ketoglutaric acid to form glutamic acid which is converted into various amino acids. The amino acids are transported to the parts above ground to form protein. It has been discovered in recent years that the root system not only absorbs nitrogen for synthesis of amino acids but also participates in the process of synthesis of proteins.

Table 128. Changes in Amino Acids and Amides (Tokari Gishi, 1960)

(a)	(b)					
	3		6		9	
	c	d	c	d	c	d
(e)	±	++	±	+++	+	±
(f)	+	++++	+	++	±	+
(g)	+	++	+	++	+	+
(h)	++	+++	+	+++	++	+
(i)	±	++	±	+	+	±
(j)	++	++	+++	+++	+	++
(k)	±	+	±	+	-	±
(l)	±	+	-	++	-	-
(m)	-	+	-	+	-	±
(n)	-	+	-	++	-	-
(o)	-	+	-	+	-	-

Note: (1) -: non-existent; ±: minimal; +: existing; [illegible]: more; +++, ++++: abundant.
(2) Analysis was the result of paper test

Key:
- (a) amino acids
- (b) number of days after roots are broken
- (c) contrast
- (d) broken roots
- (e) asparagine
- (f) glutamine
- (g) aspartic acid
- (h) glutamic acid
- (i) serine
- (j) alanine
- (k) leucine
- (l) valine
- (m) cystine
- (n) threonine
- (o) tyrosine

The results of experiments on broken roots of paddy rice listed in Table 128 show that in the normal plant only the preliminary amino acids such as glutamic acid, aspartic acid and alanine are in larger amounts and

secondary amino acids are few because these are continuously being used for synthesis of proteins. After the roots have been broken, the amount of these secondary amino acids increases visibly and large amounts of these form amides. Also, the amount of protein nitrogen drops after the roots have been broken and the amount of nonprotein nitrogen increases. From these facts it can be concluded that these are the results of hindrance to the process of formation of protein from amino acids caused by breakage of the roots. But when new roots emerge (9 days after the roots have been broken), the distribution of amino acids returns to normal. Thus it is not difficult to conclude that the root system possesses the function of maintaining the level of protein in the paddy rice plant.

How does the root actually maintain the level of protein in the paddy rice plant? Experiments indicate if the tobacco root is cut off, spraying the sap of the wound of the tobacco plant with kinetin on half of a leaf can keep the side of the leaf from turning yellow while the other side of the leaf sprayed with water turns yellow. Thus, cytokinins in the root system may be related to synthesis of proteins. Further experiments on the paddy rice showed that the root of the paddy rice plant contains four kinds of gibberellins (all belonging to cytokinins like auxins) and discovered that as the content of gibberellins in the leaves lessens, the content of chlorophyll also lessen in parallel fashion. This explains that cytokinins produced by the roots perform an important function in the synthesis of protein and are necessary to maintain the paddy rice leaves from early withering. The Shanghai Plant Physiology Institute also showed by experiment that under high temperatures (not favorable to maintaining the prosperous functioning of the root system), the use of kinetins sprayed on the surface of the paddy rice leaves can keep the leaves green and increase the 1000 grain weight. This is the physiological basis for keeping the leaves from early withering, stimulating the root system's prosperous functioning and keeping the paddy rice plant alternately dry and damp.

5. Stored substances

Observations indicate starch granules also exist in the epidermal parenchyma cells surrounding the stele of the root of the paddy rice and have the capacity of storage. But the shape of the starch granules in the cells of the root is different from the shape of those in the stem and the leaves. The starch granules in the roots appear in irregular sizes.

In general, the present understanding of the function of the roots is that the function of the root is not limited to absorption, support and storage but also includes synthesis and the root reacts with the parts of the plant above ground as a check and balance system. Studies indicate the activity of the root system is clearly related to the amount of chlorophyll in the reverse fifth leaf during heading and the second, third and fourth leaves during the milky ripe period. We can also determine the growth and function of the underground portion of the plant by observing the growth of the portion of the plant above ground and thus determine effective measures for fertilization, irrigation and field management to achieve stable and high yields.

III. Causes Affecting Absorption of the Root System

Many factors affect absorption by the root system. Factors that affect respiration of the root system in particular affect absorption to an even greater extent.

A. Aeration of the Soil

The actual effect of aeration of the soil upon the absorption by the root system is mainly its effect upon the supply of oxygen. This is because when the root absorbs nutrients it must breathe oxygen (the trihydrocarboxylic acid cycle) to supply energy. During the early and middle periods of growth of paddy rice the aerate tissues are developed and the root system can obtain oxygen via the aerate tissues. But during the latter period of growth, ducts of the aerate tissues have been destroyed and often aeration of the soil has to be relied upon to supply oxygen from the soil to sustain the normal life activities of the root system. Iwada (1957) showed by experiment that when the concentration of oxygen in the soil solutions around the roots drops, the root's absorption of nutrients also drops. In particular, the absorption of phosphorus, potassium, silicon and nitrogen drops visibly (Diagram 97).

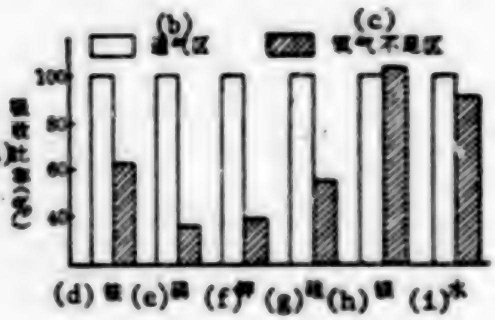

Diagram 97. Effect of Deficiency of Oxygen upon Inorganic Nutrients

Note: Compressed air was pumped into hydroponic solution to create an aerate region. The oxygen deficiency region was filled with cold water after deoxidation by boiling.

Key:
- (a) percentage of absorption (%)
- (b) aerate region
- (c) oxygen deficient region
- (d) ammonia
- (e) phosphorus
- (f) potassium
- (g) silicon
- (h) magnesium
- (i) water

Aeration and water permeability of the soil can be represented by the oxidation reduction electrical potential (Eh). The oxidation reduction electrical potential of the soil is an indicator of the soil's aeration. Aerate soil contains a lot of oxygen, its strength of oxidation is strong and its oxidation reduction electrical potential is high and vice versa.

Some people have determined that arid soils are aerated and are basically in an oxidized state. The oxidation reduction electrical potential of the entire plowing layer is high, generally above 400 millivolts. But the oxidation reduction electrical potential of the soil of paddy rice is much lower and the differences in the potential of the plowing layer are also great (Diagram 98). For example, the thin layer of soil in contact with the water surface is affected by the oxygen that is dissolved in the water and has a high oxidation reduction electrical potential, about 292 millivolts. This soil appears yellowish brown. Inside the plowing layer the oxidation reduction electrical potential reduces as depth increases and even drops to negative values so that the soil appears greenish gray or greenish purple.

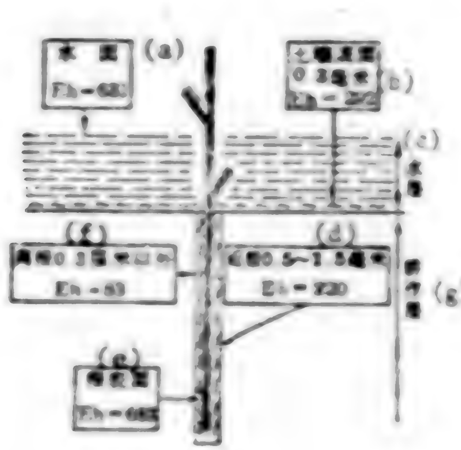

Diagram 98. Oxidation Reduction Electrical Potential in the Soil of the Paddy Rice Field (Eh unit: volt) model diagram

Key:
- (a) water surface
- (b) 0.3 millimeter above soil surface
- (c) water layer
- (d) 0.5-1.5 millimeter near the root
- (e) root surface
- (f) 0.3 millimeter away from root
- (g) plowing layer

But in the soil surrounding the white roots there is an oxidation layer with a higher oxidation reduction electrical potential surrounding the root system. This is due to the secretion of oxygen by the root system of paddy rice (on the surface of the root the Eh value can reach 683 millivolts) to assure that the root system's physiological functions of respiration and absorption are strong. But when the function of secreting oxygen by the paddy rice root system reduces and the root is unable to resist the effect of oxidation reduction, especially when the oxidation reduction electrical potential has dropped to below zero, such reducing substances

as hydrogen sulphide are formed in the soil and the root appears black. The former Pedology Institute of the Chinese Academy of Sciences (1961) showed that the electrical potential of oxidation reduction and the percentage of occurrence of black roots are negatively correlated. When the oxidation reduction potential falls below 150 millivolts, the formation of black roots quickens (Diagram 99) and the absorptive function of the root system is affected.

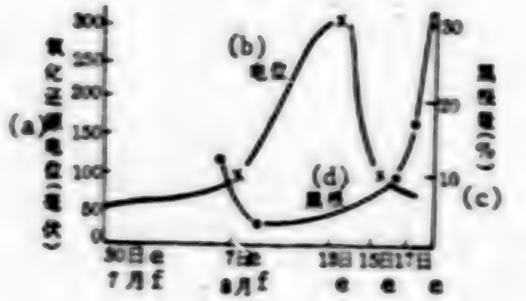

Diagram 99. Relationship Between Emergence of Black Roots and the Soil's Oxidation Reduction Electrical Potential

Key: (a) oxidation reduction electrical potential (volts)
(b) electrical potential
(c) amount of black roots (%)
(d) black root
(e) day
(f) month

B. Substances that Suppress Respiration

It has been mentioned before that when the oxidation reduction potential falls to near 0 millivolt, such reducing substances as hydrogen sulphide, formic acid, propyl acid, butyl acid and marsh gas emerge from the soil, suppressing respiration and absorption of nutrients by the root system.

Experiments show that during the tillering period of paddy rice, 30 percent of the amount of respiration is due to the function of the aerobic respiratory system's cytochrome oxidase. Absorption of inorganic elements is related to the supply of energy (ATP) produced by the cytochrome oxidase. For example, 70 percent of the absorption of potassium is due to the activity of cytochrome oxidase and the absorption of other elements is the same in the following order: Potassium > silicon > nitrate nitrogen > water. Hydrogen sulphide suppresses absorption of nutrients in the following order as noted by Mitsuyi (1951): Potassium, phosphorus > silicon, sulphur > manganese > nitrate nitrogen, water > magnesium, calcium (Diagram 100). This order corresponds to the order of absorption of inorganic elements by the cytochrome oxidase system. In addition, some experiments have shown that the use of sodium cyanide NaCN and sodium supernitride (NaN_3) that suppress aerobic respiration also cause similar suppression of absorption of inorganic ions. Thus, the selective suppression of the absorption of inorganic ions

by hydrogen sulphide is mainly due to the suppression of the activity of the cytochrome oxidase in the aerobic respiratory system.

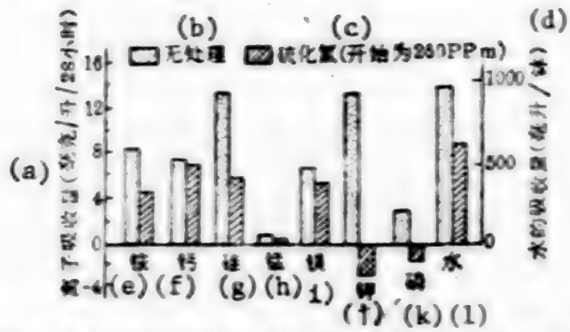

Diagram 100. Effect of Hydrosulphide Upon Absorption of Water and Inorganic Ions in Paddy Rice

Key: (a) absorption of ions (milligram/liter/28 hours)
(b) not treated
(c) hydrosulphide (260 ppm beginning)
(d) absorption of water (milliliter/pot)
(e) ammonium
(f) calcium
(g) silicon
(h) manganese
(i) magnesium
(j) phosphorus
(k) water
(l) potassium

But when there is ferric oxide, hydrogen sulphide combines with iron to form ferric sulphide and to a certain degree this prevents damage caused by hydrogen sulphide (formation of black roots). When the amount of iron in the soil is small and the membranous coating of ferric oxide is very thin, the root's absorption of nutrients will be hindered and the roots will rot. In addition, hydrogen sulphide is often absorbed by the paddy rice plant and directly causes adverse effects upon young panicle formation.

Formic acid, propionic acid and butyric acid (which easily occur when organic fertilizers that have not been made into compost are used) function similarly as hydrogen sulphide. For example, butyric acid inhibits absorption of inorganic ions and water in the following order: Potassium, phosphorus > silicon > manganese > nitrogen (ammonia), water > magnesium and calcium. The effect differs from that of hydrogen sulphide in that respiration of the roots is intensified while oxidation and phosphatization reactions lessen and the production of ATP is reduced, even causing the roots to rot.

To prevent respiratory suppressing substances from hindering the absorption of inorganic elements and moisture, the broad masses of the laboring people use compost and fermented fertilizers, smooth, weed and dry the fields, alternate dryness and wetness in the field by controlling irrigation and increase permeability of water by placing drains underneath the

fields as effective measures to raise the oxidation reduction electrical potential.

Recently, it has been learned that the absorption of phosphorus by the paddy rice root is related to the formation of high energy phosphate bonds in the oxidation and phosphatization reactions in the process of respiration. The absorption of potassium is related to metabolism of nuclei acid. The absorption of nitrogen is related to the trihydrocarboxylic acid cycle. Thus, substances that suppress these metabolic activities will all affect respiration and absorption by the root system.

C. Daylight

Respiration by the root system consumes the product of photosynthesis of the upper part of the plant--sugar. Thus, daylight that affects photosynthesis of the upper part of the plant also indirectly affects respiration of the root system. This in turn affects the absorption of various inorganic nutrients by the root system.

Tagahashi et al (1962) showed by experiment that as the intensity of light is reduced, the absorption of inorganic elements also reduces. Under 26 percent intensity of light, the amount of absorption of nitrogen, phosphorus and potassium dropped to between 30 percent and 40 percent of the original amounts (Table 129).

Table 129. Effect of Light Upon the Absorption of Inorganic Elements by the Root System (%)

照度指数 (a)	N	P_2O_5	K_2O	CaO	MgO	MnO	SiO_2
100	100	100	100	100	100	100	100
58	82.5	76.3	77.8	106.9	103.0	85.1	95.3
26	40.4	33.0	41.0	63.9	68.2	46.2	65.1
5	16.5	14.8	13.0	48.5	40.2	22.2	84.9

Key: (a) Light Intensity Index

D. Temperature

The most suitable temperature for respiration by paddy rice is generally 30°C. Low temperatures reduce metabolic activity and respiration of the root system, causing a reduction in the absorption of inorganic nutrients. When the temperature drops from 30°C down to 14°C, the amount of phosphorus absorbed is reduced by 50 percent and the amount of nitrogen and potassium is reduced by 25 percent to 30 percent. Papa (1953) showed that temperatures below 24°C or higher than 37°C to 39°C affect the absorption of inorganic elements and especially silicon, potassium, phosphorus and nitrogen to a greater extent (Diagram 101).

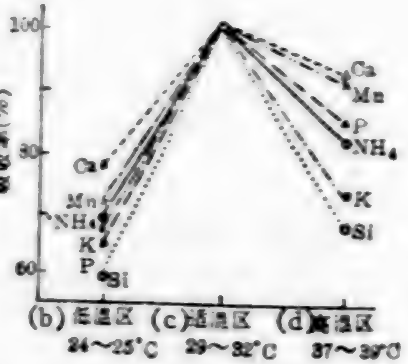

Diagram 101. Effect of Water Temperatures on Absorption of Mineral Elements by the Paddy Rice Plant

Key: (a) percentage of absorption (%) (d) high temperature zone
(b) low temperature zone
(c) suitable temperature zone

E. Salt

The effect of salt upon the absorption by the root system is due to the fact that salt causes the osmotic pressure in the environment to become greater than the osmotic pressure of the cells of the roots, causes physiological dryness and hinders absorption and transpiration of moisture and absorption of nutritive elements by the root system. The order of suppression of absorption of nutrients by sodium chloride is: water > K_2O > P_2O_5 > > NH_4.

Paddy rice is weakly tolerant to salt during the young seedling period. The critical concentration of salt in that period is 0.09 percent. The critical concentrations of salt during the panicle bearing, flowering and fruiting periods are 0.25 percent, 0.27 percent and 0.28 percent respectively.

F. Nutritional Condition

Absorption of inorganic ions is affected not only by the external environment but also by the nutritional condition of the plant itself. The absorption of nitrogen, phosphorus and potassium is affected the most. Mitsuyi (1957) showed by experiment that denying the paddy rice plant nitrogen, phosphorus, potassium and calcium respectively during the peak growth period greatly reduced the plant's ability to absorb other elements (Table 130). Table 130 also shows the importance of combination of nitrogen, phosphorus and potassium.

Table 130. Effect of Nutritional Conditions Upon the Absorption of Ions (%)

(a)	事先无处理	缺(b)氮	缺(c)磷	缺(d)钾	缺(e)钙
水的吸收 (f)	100	86	84	66	87
氮的吸收 (g)	100	82	52	49	44
磷的吸收 (h)	100	28	209	122	56
钾的吸收 (i)	100	22	67	185	30

Key: (a) without prior treatment
(b) deficiency of nitrogen
(c) deficiency of phosphorus
(d) deficiency of potassium
(e) deficiency of calcium
(f) absorption of water
(g) absorption of nitrogen
(h) absorption of phosphorus
(i) absorption of potassium

IV. Patterns of Paddy Rice's Need for Fertilizers and Principles of Fertilizer Application

Paddy rice is a crop that needs relatively abundant amounts of fertilizers. We must not only understand what fertilizers are needed by paddy rice and the function of the fertilizers but more importantly we must understand the patterns of need for fertilizers by paddy rice and apply fertilizers reasonably to satisfy that need throughout the life of the rice plant in order to realize high yields of paddy rice.

A. Patterns Paddy Rice's Need for Fertilizers

1. The amount of fertilizers needed by paddy rice

It has been mentioned before that paddy rice needs nitrogen, phosphorus, potassium, silicon, calcium, magnesium, sulphur, boron and zinc. Some of these elements exist in the soil in abundance and are provided by nature while others that are needed in abundance require human application. Generally, the elements most deficient in the soil are nitrogen, phosphorus and potassium, usually called the three essential elements (fertilizers). Nankai University (1955) showed that a paddy rice plant in a field producing 1000 jin per mu has to absorb pure nitrogen (N) in amounts between 18 and 25 jin, phosphorus (P_2O_5) in amounts between 11 and 13 jin and potassium (K_2O) in amounts between 21 and 23 jin.

The amount of fertilizers to be applied must be analyzed according to the soil, climate, varieties and techniques of cultivation. In the Shanghai region, the base manure for each mou of double cropped rice consists generally of 80 to 100 dan of grass and pond mud and 30 jin of calcium superphosphate in addition to 40 to 60 jin of ammonia water as a surface fertilizer. Three to four days after transplanting, 35 to 40 jin of ammonium acid carbonate is applied as a sidedressing. Five to six days after the

Table 131. Relationship Between Absorption of the Three Basic Elements and Paddy Rice Production

品种 (a)	产量 (b)(斤/亩)	(c) 三要素吸收量		
		(d)氮	e 磷(P_2O_5)	钾(K_2O) f)
稻 g 草	1058	9.5	2.3	18.6
稻 h 谷	1043	15.2	9.2	2.6
总 i)计		24.7	11.5	21.2

Note: Variety measured was "Yinfang."

Key: (a) type
(b) Yield (jin/mu)
(c) Amount of absorption of the three basic elements
(d) nitrogen
(e) phosphorus
(f) potassium oxide
(g) straw of rice plant
(h) rice grain
(i) Total

first sidedressing, 15 to 20 jin of ammonium acid carbonate is applied as the second sidedressing ("catching the yellow spots"). Fifteen jin of ammonium acid carbonate or ammonia water (flow through irrigation) are applied as sidedressing to plants that grow weakly during mitosis (fertilizers for panicles) or after heading (pellet fertilizers). At present, the total amount of fertilizers equivalent to 80 to 100 dan of standard fertilizers per mu (fertilizers of pig manure quality) will bring about higher yields (Diagram 102).

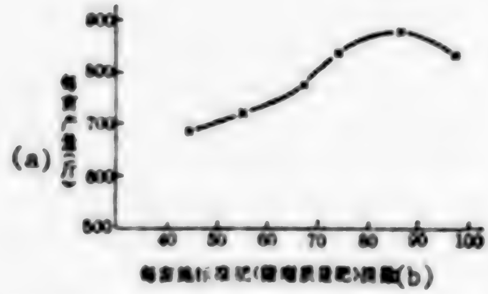

Diagram 102. Amount of Fertilizers Applied and Relationship to Yield (Statistics of Shanghai Municipality's 36 plots of late season rice)

Key: (a) yield per mu (jin)
(b) number of dan of standard fertilizer (pig manure quality fertilizer) applied per mu

2. The need for fertilizers during each growth stage of paddy rice

Some people have shown by experiment that the speed of absorption of various nutrients reaches its peak before heading. This is shown in Diagram 103 compiled from measurements of the content of inorganic nutrients in the part of the plant above ground at 10-day intervals in the paddy rice field (the total amount of absorption per plant) and calculations of the amount of absorption per day (speed of absorption). Taking the heading period as the demarcation line, the speed of absorption slows down after that period. Of the various nutrients, nitrogen, potassium and phosphorus are absorbed the most rapidly and are absorbed early. The peak of absorption of these elements occurs about 20 days prior to heading while the absorption peak of magnesium, sulphur and iron occurs ten days later and the peak absorption periods of silicon and manganese occur even later.

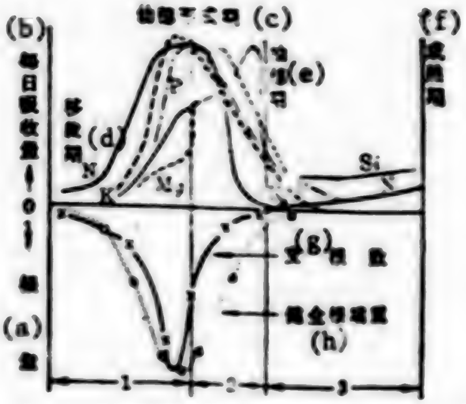

Diagram 103. Speed of Absorption of Nutrients During Each Growth Period of Paddy Rice

Key: (a) amount
(b) daily absorption of roots
(c) period of young panicle formation
(d) transplanting time
(e) heading period
(f) maturity period
(g) number of rootings
(h) weight of healthy root tips

Zhongshan University (1955) also discovered a similar pattern for the absorption of more nitrogen, phosphorus and potassium during the early growth period (from transplanting to tillering) and the middle growth period (from young panicle differentiation to heading) and less during the latter growth period (fruiting and maturation periods). But there is a definite difference between early and late rice (Table 132).

3. Conversion of fertilizers in the paddy rice field

Since paddy rice grows in submerged soil, draining away the layer of water permits formation of an oxidation layer several millimeters thick on the

surface of the soil in the plowing layer of the paddy field where oxygen exists. It also permits the formation of a reducing layer below that which lacks oxygen. This soil condition will cause changes in the amount of fertilizers in the soil and affect the supply of inorganic nutrients for paddy rice.

Ammonium fertilizers applied on the surface of the field (such as ammonium sulphide, ammonium acid carbonate) partially enter the reducing layer and are absorbed by the paddy rice plant. The other parts are converted in the oxidizing layer into nitrate nitrogen (NO_3^-). This nitrate nitrogen often permeates into the reducing layer, is converted to nitrogen gas and becomes lost in the air after being denitrified by denitrifying bacteria (Diagram 104). Large amounts of nitrogen fertilizers are lost this way. This may be the cause of stunting in paddy rice seedlings. To reduce the loss, nitrogenous fertilizers should be applied deeply (so that the percentage of utilization of nitrogenous fertilizers can be raised from 30 percent to 50 percent) or a synergist could be added to the nitrogen fertilizer (to suppress denitrification). If nitrogen fertilizers are applied as a sidedressing, the field should be weeded immediately so that the fertilizers can be mixed into the soil layer to avoid conversion of ammoniacal nitrogen into nitrate nitrogen. It can be seen here that in the paddy rice field, ammoniacal nitrogen is more stable than nitrate nitrogen and can be more easily absorbed.

Table 132. Percentage of Absorption of Nitrogen, Phosphorus, Potassium During Each Growth Period of Double Season Rice (%)

稻别 (a)	生育期 (b)	(c) 平均本期吸收量占总吸收量的%		
		(d) 氮	(e) 磷	(f) 钾
早稻 (g)	移栽至分蘖期 (i)	35.5	15.7	21.9
	幼穗分化至抽穗期 (j)	48.6	57.0	61.9
	结实成熟期 (k)	16.0	24.5	16.2
晚稻 (h)	移栽至分蘖期 (i)	22.3	15.9	20.5
	幼穗分化至抽穗期 (j)	58.7	67.4	51.8
	结实成熟期 (k)	19.0	26.7	27.7

Key:
- (a) Type of rice
- (b) growth period
- (c) average amount of absorption in growth period as percentage of total amount absorbed by plant %
- (d) nitrogen
- (e) phosphorus
- (f) potassium
- (g) early rice
- (h) late rice
- (i) transplanting to tillering
- (j) panicle differentiation to heading
- (k) fruiting and maturity

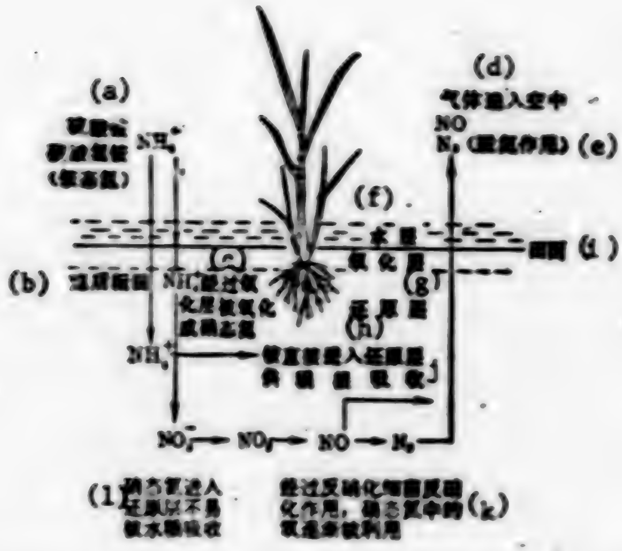

Diagram 104. Conversion of Nitrogen in Watered Paddy Soil

Key: (a) ammonium sulphate (ammonium hydrocarbonate (ammoniacal nitrogen)
(b) weeding after application
(c) oxidized by oxidizing layer to become nitrate nitrogen
(d) No gas enters air
(e) (dentrification)
(f) water layer
(g) oxidizing layer
(h) reducing layer
(i) field surface
(j) ammonia reenters the reducing layer directly for roots to absorb
(k) by dentrification of denitrifying bacteria, oxygen of nitrate nitrogen is gradually utilized
(l) nitrate nitrogen entering reducing layer cannot easily be absorbed by rice plant.

Conversion of fertilizers in the paddy rice field also increases the amount of available phosphorus. This is because hyperferric phosphate is reduced to easily soluble hypoferric phosphate and also because the phosphate radical in hyperferric phosphate and aluminum phosphate can be replaced by other ions.

Silicon in the forms of $Si(OH)_4$ can be absorbed by aluminum hydroxide or ferric hydroxide which has newly settled and can combine with hypoferric hydroxide to form synthetic substances. These synthetic substances can release silicon in soil that is strongly reducing and is submerged under water so that the paddy rice root can absorb it.

In addition, after submerging the field in water, the concentration of ions in the solutions in the soil of the rice field is increased. These ions are mainly K^+, Ca^{++}, Mg^{++}, Na^+, NH_4^+, Fe^{+++} and HCO_3^-. The increase is caused by the exchange reactions between dissolved carbon dioxide in the solutions of the soil and the positive ions.

In general the content of ammoniacal nitrogen is relatively stable in the paddy rice field. When the supply of inorganic elements such as phosphorus, potassium, silicon, calcium and magnesium increases, the growth of paddy rice will be benefited. Nitrogen is easily denitrified and lost. In newly opened rice fields the nutrients easily and rapidly decompose (thus more organic fertilizers should be applied). At the same time, the activity of anaerophytobionts in the reducing layer increases the reducing strength of the soil. The formation of such reducing substances as hydrogen sulphide, formic acid, butyric acid and marsh gas are harmful to the paddy rice root. In production, these adversities must be overcome.

4. Transportation and reutilization of inorganic elements

When the paddy rice plant is deficient in nitrogen, we often can see the lower leaves begin to yellow and wither early while the newly emerged leaves still remain green. This is because when nitrogen is deficient, the chlorophyll and protein in the lower leaves are decomposed and nitrogen is transported to the new leaves for reuse. But transportation and reutilization of some inorganic elements are not as obvious as those of nitrogen. Studies of absorption and transportation of massive amounts of elements in the paddy rice fields show that these elements can be classified into three categories:

The first category includes nitrogen, phosphorus and sulphur that make up proteins. Since they are related to cell division and growth of the plant, they are massively absorbed beginning with the vegetative growth stage of the paddy rice plant. Massive absorption continues through young panicle differentiation until the time of heading and flowering. After flowering, the elements in the stems and leaves are again transported to the panicles. They are the most easily transported and most easily reutilized elements in the paddy rice plant. In particular, phosphorus is the most mobile element in the paddy rice plant. Studies indicate after phosphorus is first absorbed by the plant it enters the part of the plant where growth occurs. When the content of phosphorus becomes too high the element enters the lower leaves. When the supply of phosphorus ceases, the phosphorus in the lower leaves is transported to the upper leaves. Because nitrogen and phosphorus can be easily transported, their deficiency, during the latter period of growth, should be prevented so that these elements will not be transported too early from the lower leaves to the upper leaves causing early withering. Too much phosphorus and nitrogen must also be avoided to prevent an over prospherous nitrogen metabolism in the lower leaves which causes the plant to remain green and mature late.

The second category includes potassium and calcium. They do not easily move about, especially calcium which is the most immobile. Thus these elements must be continuously absorbed from the beginning of growth to maturity.

The third category includes magnesium which is in between the first and the second categories in mobility.

5. Changes in the activities of carbon and nitrogen during each growth period of paddy rice.

We have already mentioned above that the absorption of inorganic elements during each growth period of paddy rice follows a pattern. This is related to the change in the center of growth of the paddy rice plant (the center of distribution of inorganic elements and organic nutrients) causing a change in the activities of carbon and nitrogen in each of the organs during each growth period.

Diagram 105 shows the activities of protein (nitrogen) and starch (carbon) in the organs of each growth period of paddy rice. Diagram 105 shows nitrogen and carbon change according to the following pattern during each period of paddy rice growth.

(1) The early growth period of the vegetative growth stage is the most active period of nitrogen metabolism in the life of the paddy rice (absorption, assimilation and decomposition of nitrogen). Nitrogen absorbed by the root enters the center of growth en masse--the leaves and the tillers, for synthesis of protein, to develop root, leaves and tillers. This is when the content of protein in the leaves and the leaf sheaths reaches a peak. This is why this stage needs more nitrogen fertil[illegible]rs because photosynthetic products are being used for synthesis of protein (supplying organic acids and energy). Carbon (starch) does not accumulate much during this period.

(2) During the middle growth period, the paddy rice plant converts its vegetative growth into reproductive growth and the center of growth moves from the leaves and tillers to the formation of panicles (secondary growth involves the flag leaf and elongation of the stem). At this time, the stem, leaves and roots that grew rapidly during the previous period need a definite amount of structural substances such as cellulose so that the tissues will become strong and aged and the ability to resist lodging and disease will be strengthened. On the other hand, large amounts of carbohydrates are needed to serve as the source of carbon and energy for the formation and development of young panicles, pollen and embryo sac. Thus, the growth of the plant enters the carbohydrate metabolism stage. The content of starch in the stems and the leaf sheaths gradually increases. But at the same time a certain level of nitrogenous nutrients must be maintained to stimulate development of the reproductive organs (reduce degeneration of spikelets) and the elongation of the stems. Drying the fields during this period is a measure to control the absorption of nitrogen, reduce the formation of protein and suppress ineffective tillering so that photosynthetic products

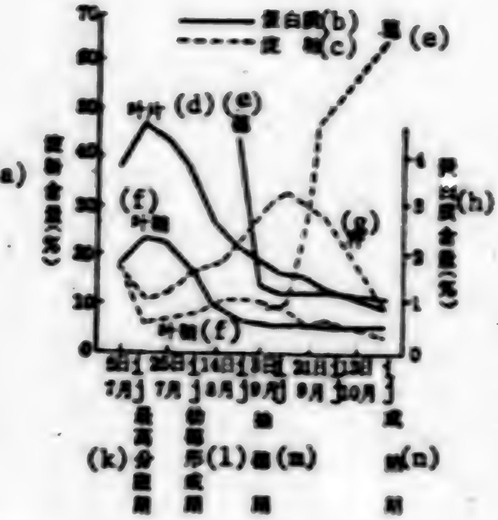

Diagram 105. Changes in Contents of Protein and Starch in the Growth Process of Paddy rice

..... starch ———— protein

Key: (a) content of starch (%)
(b) protein
(c) starch
(e) panicle
(f) leaf sheath
(g) stem
(h) content of protein (%)
(i) day
(j) month
(k) highest tillering period
(l) young panicle formation period
(m) heading period
(n) maturation period

are made available for the synthesis of carbohydrates. At the end of this period carbon and nitrogen metabolism that is regulated well will cause a lot of starch to accumulate in the stem and the leaf sheaths, even reaching 30 percent of the dry weight of the stem.

(3) The latter period of growth is still mainly the period of carbon metabolism. Maintenance of a certain level of nitrogenous nutrients will keep the leaves green and prevent the leaves from early withering so that more photosynthetic products can enter the grains. This is because after heading, the center of growth has moved to the grains. Although a certain amount of protein also accumulates in the grains, the major activity is the accumulation of starch (constituting over 70 percent of the dry weight of the grain). Under normal conditions, vegetative growth basically ceases. Photosynthetic products mainly in the form of sugar are transported to the grains and are stored in the grains as starch.

In each of the periods described above, changes in carbon and nitrogen caused by the shift in the center of growth are also reflected by the change in the color of the leaves. Double season rice growing normally will have a very active nitrogen metabolism during the prosperous tillering period. The color of the leaves are dark and a first "blackening" appears. During the young panicle differentiation period, nitrogen metabolism reduces and carbon metabolism increases. The color of the leaves lightens and a first "yellowing" appears. During the panicle bearing stage, the major activity is carbon metabolism but nitrogen metabolism increases slightly (for growth of panicles) and the color of the leaves turns dark again and a second "blackening" appears, but lighter than the first. Before heading, carbon accumulates (for flowering and fruiting) and a second "yellowing" appears. Observations by the Shanghai Municipal Academy of Agricultural Sciences indicate that the degree of color of the leaves of early rice changes from grade 2 at time of transplanting to between grades 3.5 and 4 after sidedressing. The color of leaves changes back to grade 2 yellow after the field is held [water withheld] and back to grade 3 green after the field is reirrigated to "catch the yellow spots.' The color of leaves lightens again to grade 2.5 green before heading. In general, as the carbon and nitrogen metabolism changes, leaves of double season rice manifest the alternate color pattern of "black-yellow-black-yellow," the so-called "two blackening and two yellowing" pattern. This pattern is an important reference for grasping the management of fertilization and irrigation in the production of paddy rice.

B. Principles of Application of Fertilizers for Paddy Rice

In paddy rice production, a deficiency of fertilizers will make high yields impossible. Raising the level of fertility without proper application will also make high yields impossible. A reasonable application of fertilizers means to fully develop the effect of increasing the yield by such application so that the fertilizers will be fully utilized to produce a higher yield. The amount of yield resulting from absorption of a unit amount of fertilizers by the crop is called the productivity of fertilizers (under ordinary conditions, the productivity of fertilizers of nitrogen (N_2), phosphorus (P_2O_5) and potassium (K_2O) applied to paddy rice is 56, 108 and 54 respectively). A reasonable application of fertilizers must take into consideration the productivity of fertilizers during the different growth periods as well as the climate, the geographical condition and growth of the seedlings.

1. Multiplicity of paddy rice types

Our nation is expansive and many types of paddy rice exist: early rice, late rice, intermediate rice and single season late rice which all have visibly different growth periods. In the Shanghai area, the single season late rice was the main crop in the past but now double season rice is the absolutely dominant crop. A comparison of their growth periods separated into three stages (Table 133) shows there is little difference between the number of days of reproductive growth and mature growth. The major difference is the length of the vegetative growth period (the length of the early rice period is more than double the single season late rice). During this

Table 133. Comparison of the Times of Growth of Single Season Late Rice and Double Season Rice (Shanghai Municipal Academy of Sciences, 1976)

类型 (a)	代表品种 (b)	全生育期 (c)	营养生长期 (d) / (e) 育秧→移栽→最高分蘖→幼穗分化→开花→收获	生殖生长期 (f)	成熟生长期 (g)
(i) 单季晚稻	(j) 农垦58	170 天 (h)	30 35 30; $\underbrace{35\ 30}_{65}$; 95天 (h)	33天 (h)	43天 (h)
(k) 后季稻	(l) 嘉农14	140 天 (h)	45 15 ±5; $\underbrace{15\ \pm5}_{10-20}$; 55-65天 (h)	33天 (h)	43天 (h)
(m) 早稻(三熟制)	(n) 矮南早一号	93 天 (h)	30 15 -5; $\underbrace{15\ -5}_{10}$; 40天 (h)	29天 (h)	24天 (h)

Key:
(a) type
(b) representative variety
(c) total growth period
(d) vegetative growth
(e) seedling cultivation ⟶ transplanting ⟶ highest tillering ⟶ ⟶ young panicle differentiation ⟶ flowering ⟶ harvest
(f) reproductive growth period
(g) maturing period
(h) days
(i) single season late rice
(j) Nongken 58
(k) late season rice
(l) Jianong 14
(m) early rice (triple cropping)
(n) Ainanzao No 1

period, the difference in time is most obvious from transplanting to young panicle differentiation. The single season late rice requires 65 days and early rice requires only 10 days. Because of this situation, double season rice did not require separate applications of fertilizers for tillering, for growth in thickness, for growth of panicles each of which having its own characteristics as the single season late rice does.

2. The characteristics of absorption of fertilizers of double season rice and the methods of fertilization

Because double season rice has a short growth period, its beginning period of growth must be "robust" enough (the plant must tiller early and grow

rapidly), its middle growth period must be "steadfast" (rapid conversion from nitrogen metabolism to carbon metabolism) and in the latter growth period the plant must "not wither early" (the plant should mature while the plant is still green and alive).

These growth characteristics of double season rice determine the pattern of absorption of fertilizers. Experiments indicate the absorption of fertilizers by double season rice is most active during the preliminary growth period (Diagram 106). For example, early rice "Ainanzao No 1" absorbs 0.6 to 0.7 jin of nitrogen per mu daily during its early growth period, 2 to 3 times as much as that during the latter period of growth. Late season rice variety "1404" ("Jingyin 66" x "Shuangfeng No 1") absorbs 0.4 to 0.6 jin of nitrogen per mu daily beginning from the 10th day after transplanting and continuing for 10 days. This characteristic of the need for fertilizers of double season rice makes it necessary to pay special attention to the quality of base manure and the method of fertilization.

According to the pattern of need for fertilizers of double season rice, fertilization of the Shanghai area's double season rice involves application of a rich base manure (organic fertilizer), quick surface fertilizer (ammonia water), early sidedressing (chemical fertilizer), controlling fertilization during the middle growth period and application of fertilizers for the panicles according to the growth conditions of the seedlings during the latter period of growth. Surface fertilizers and sidedressings stimulate nitrogen metabolism during the early period, early tillering and rapid growth. Base manure assures the persistent and stable release of large amounts of various elements during the middle and latter period of growth so that nitrogen metabolism can change into carbon metabolism, growth will be stable and early withering will not occur. In practice, about 60 percent to 80 percent of the fertilizers (mostly organic fertilizers containing mainly the various elements) are applied as base manure during preparation of the field. The other 30 percent of fertilizers (mainly fast action fertilizers) are applied during the early period (tillering period) in 1 or 2 sidedressings to stimulate the early tillering and rapid growth of tillers to suit the short vegetative growth period of double season rice. In the Shanghai region, this method of applying most of the fertilizers during the early period of tillering as sidedressings is called "heavy application at the beginning."

To heighten the percentage of utilization of fertilizers, especially by late cropping late season rice, larger ratios of fertilizers as base manure (including the fast action nitrogen fertilizers originally used as sidedressings) were experimentally applied in the deep layers of the soil (called deep application of base manure in the entire plowing layer), resulting in a definite increase in yield. But in soils of high fertility, the ratio of deep application of fast action nitrogen fertilizer originally used for sidedressing but not used as a base manure produced the best result when the ratio was 60 percent (with the remaining 40 percent as sidedressing). This prevented overly strong aftereffects which would cause the paddy rice plant to lodge.

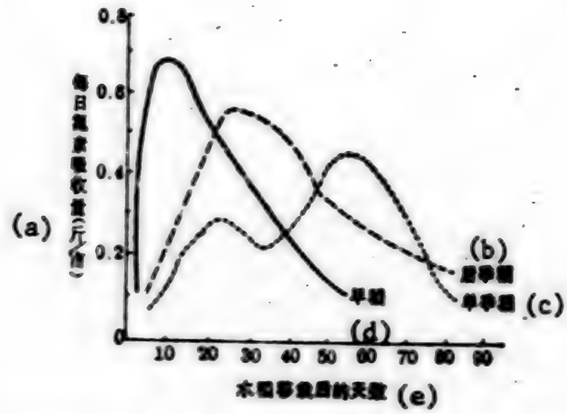

Diagram 106. Absorption of Nitrogen by Different Types of Paddy Rice (Shanghai Municipal Academy of Agricultural Sciences, 1975)

Key: (a) daily amount of absorption of nitrogen (jin/mu)
(b) late season rice
(c) single season rice
(d) early rice
(e) number of days after transplanting

3. Characteirstics of absorption of fertilizers of hybrid rice and methods of fertilization

Hybrid rice possesses strong rooting and tillering strengths. In production, only 30,000 to 40,000 basic seedlings per mu are sufficient to produce high yields because the yield is mainly dependent upon the large amounts of tillers that form panicles. Thus, under oridinary conditions, heterosis can be developed fully only when more amounts of fertilizers are applied to hybrid rice than to ordinary rice. Preliminary experiments conducted by the Hunan Provincial Hybrid Rice Research Coordination and Cooperation Group and the Guangzi Agricultural Academy's Paddy Rice Heterosis Utilization Research Group at various places indicate hybrid intermediate rice in fields producing 1000 jin per mu needs 30 to 35 jin of pure nitrogen, hybrid late season rice needs 25 to 30 jin of pure nitrogen and the most suitable ratio of nitrogen, phosphorus and potassium is 1.5:1:1 or 1:0.8:1.1 (Table 134).

Table 135 shows the amount of absorption of nitrogen, phosphorus and potassium during each growth stage of hybrid paddy rice. Hybrid rice still absorbs 24.62 percent nitrogen after full heading. Thus, a higher nitrogen level can be maintained during the plant's latter period of growth, reducing the burden by the grains to obtain nitrogen from the roots, stem and leaves. This makes it possible for the plant to stay green at maturity, avoid early withering and heighten the content of protein in the grains.

Table 134. Effect of Different Amounts of Application of Nitrogen, Phosphorus, Potassium and Ratio of Application Upon Yield of Hybrid Paddy Rice (Hunan Provincial Pedology and Fertilizer Institute, 1977)

(a) 肥种类			N:P:K	有效穗	每穗	千粒重	产量	谷/草
N (斤/亩) (b)	P_2O_5 (斤/亩) (b)	K_2O (斤/亩) (b)	比例 (c)	(万/亩) (d)	实粒数 (e)	(克) (f)	(斤/亩) (g)	(h)
10.5	5.8	4.9	2:1:0.9	18.38	137	26.0	1179.5	0.98
22.5	15.0	15.0	1.5:1:1	18.63	156	26.1	1314.0	1.06
34.5	21.0	21.0	1.6:1:1	22.85	131	26.3	1253.3	0.83
34.5	15.0	28.0	2.3:1:1.8				1261.0	
46.5	15.0	28.0	3.1:1:1.4	[illegible] 63	126	26.1	1185.3	0.90

Note: (1) Variety: Nanyou No 2 (intermediate rice)
(2) Medium level fertility red loam paddy field
(3) Data of equivalence of nitrogen, potassium and phosphorus do not include original content in the soil

Key: (a) type of fertilizers
(b) (jin/mu)
(c) ratio
(d) effective panicles (10,000/mu)
(e) number of filled grains per panicle
(f) 1000 grain weight (gram)
(g) yield (jin/mu)
(h) Grain/straw

This is also beneficial to strengthening photosynthesis of the leaves, benefits the transportation of photosynthetic products, strengthens resistance to disease and lodging and raises the fruiting percentage and the weight of grains.

Hybrid rice is characterized by a strong photosynthesis during the early growth period, low respiration in daylight and low intensity of respiration. In hybrid rice nutrients accumulate in abundance, consumption of nutrients is minimal, rooting is fast, tillers occur early and plentifully and the leaves grow and expand rapidly to acquire a large leaf surface area. Thus, cultivation of hybrid rice should emphasize the early growth period to create conditions favorable for strong seedlings so that growth will be stable and strong, early tillering and rapid development of appropriately aged tillers. Fertilization should emphasize the heavy application of compost or organic fertilizers that easily become compost as a base manure with small amounts of surface fertilization and early sidedressings for tillering. During the middle growth period, sidedressing for the formation of large panicles should be applied. Because during the latter period of growth the transportation of nitrogen and phosphorus from the leaves is slow and the leaves do not

easily wither early, sidedressing during the latter period of growth must be in small amounts and must be applied carefully. Generally sidedress the roots during the beginning period of heading and flowering periods. Sidedressing will raise the percentage of fruiting and the weight of the grains. The ratio of fertilization during each period of growth consists of 60 percent of the total amount of fertilizers applied as base manure and surface fertilizers with 20 percent to 30 percent being applied as sidedressings during the early growth period, and 10 percent to 20 percent applied as sidedressings during the latter growth period.

4. Combined use of various fertilizers

It has been mentioned earlier that the inorganic nutritional elements necessary to the paddy rice plant do not function independently and their effects are not simply additive but are mutually related, mutually limiting and function as a whole. Without one, the plant will not grow properly. For example, raising the level of nitrogenous fertilization requires elevating the level of fertilization of phosphorus, potassium and silicon so that the normal ratio of potassium and nitrogen and the ratio of silicon and nitrogen in the body of the paddy rice plant can be maintained for the paddy rice plant to grow strong and healthily. If the soil lacks a certain element, no matter how abundant the other elements are, growth of the paddy rice plant will still be governed by the element that is lacking. Thus, in production the combined application of various fertilizers must be taken into consideration and major problems and conflicts must be discovered.

In fertilization of paddy rice, combination of fertilizers must take the following into consideration:

(1) Combined application of nitrogenous, phosphorus and potassium fertilizers: Increasing the application of nitrogen fertilizers effectively increases the yield of paddy rice. In places where the level of fertilization is low, the results are more obvious. However, when the increase in the application of nitrogen fertilizers reaches a certain level, the productivity of fertilizers visibly drops. This is because the balance of the various elements in the plant has been disturbed. Under this situation, the amount of application of other elements must be increased, especially the amount of phosphorus and potassium.

Table 135. Percentage of Absorption of Nitrogen, Phosphorus, Potassium During Each Growth Period of Hybrid Paddy Rice (%) (Hunan Provincial Pedology and Fertilizers Institute, 1977)

(a)	(b)	(c)	(d)	(e)	(f)
(g)	1.60	34.96	30.59	8.23	24.62
(h)	1.01	17.10	43.21	10.00	28.70
(i)	1.00	26.10	44.50	9.60	19.20

Note: Variety tested was "Nanyou No 2" (intermediate rice). The field was of medium fertility red loam

[Key on following page]

[Key to table 135 on preceding page]

(a) type of fertilizers
(b) sowing to transplanting
(c) transplanting to peak tillering
(d) peak tillering to beginning panicle bearing
(e) beginning panicle bearing to full heading
(f) full heading to maturity
(g) nitrogen
(h) phosphorous
(i) potassium

The combination of nitrogen, phosphorus and potassium depends upon the ratio of nitrogen, phosphorus and potassium fertilizers. Chemical analysis of harvested rice in the past shows that the ratio among nitrogen, phosphorus and potassium should be 1:0.5:1. In actual application, the capability of the soil to supply nitrogen, phosphorus and potassium must be taken into consideration. For example, paddy rice fields in the Shanghai area generally are not deficient in phosphorus but when the level of nitrogen is raised, the amount of phosphorus should also be raised to obtain better results in increasing the yield of paddy rice. At the same time, the phosphorous fertilizer most commonly used at present is calcium superphosphate. This fertilizer not only provides phosphorus for the paddy rice plant but at the same time provides boron, iron, zinc and molybdenum which are microelements important to the physiological functions of paddy rice. Thus, the application of phosphorus fertilizer, especially the deep application of calcium superphosphate as a base manure for the entire plowing layer, is very effective for increasing yield.

(2) Combined application of inorganic fertilizers and organic fertilizers: Inorganic fertilizers are highly concentrated, very effective, simple in composition, release nutrients fast and can be absorbed and utilized by the paddy rice plant immediately after being applied in the rice field. This type of fertilizer is good as a sidedressing for double season rice in "heavy application at the beginning" or for solving the deficiency of a certain element which causes a physiological hindrance to the growth of paddy rice. But their effectiveness does not last and when too much is applied they cause adverse effects.

The greatest advantage of organic fertilizers is their rich content and their ability to release various elements on an overall scale, slowly and continuously for the growth and development of paddy rice. At the same time, two-thirds of the amount of nitrogen needed by the paddy rice plant come from the soil. The massive amounts of silicon needed also come from organic fertilizers (the ash in the straw of the paddy rice plant contains over 70 percent silicon dioxide). Thus, organic fertilizers are significant to the growth of paddy rice. In addition, studies conducted by the Nanjing Pedology Institute of the Chinese Academy of Sciences and the Jiangsu Wuxi Agricultural School indicate that the products of decomposition of grass and pond mud can combine with iron and neutralize the poisonous effect of iron upon the paddy rice plant, reduce the adverse effect of iron upon phosphorus and correspondingly raise the fertilizing effect of phosphorus. The Shanghai Plant Physiology Institute also discovered that in

soil with organic fertilizers, entry of phosphorus 32 into the roots is four times as fast per hour than that entering the roots of the plant in soil without any organic fertilizers and the speed of transport of phosphorus 32 to the upper part of the plant above ground is seven times faster. But because organic fertilizers release elements much slower, they generally serve best as base manure.

The characteristic of mutual stimulation and mutual supplement of inorganic and organic fertilizers indicates the importance of a combined application. Experiments at various localities also prove that using organic fertilizers as the main fertilizer and inorganic fertilizers as the supplementary one in combination is an important principle of fertilization for realizing high yields of paddy rice.

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CHAPTER 9. PHYSIOLOGICAL BASIS FOR CONTROL OF WATER AND MUDDINESS

A popular saying says: "Paddy rice, paddy rice, live water grows rice." Water is particularly significant to the growth and development of paddy rice. This is not only manifested in the fact that paddy rice needs to grow in a layer of water but it is also manifested in the function of the water layer in regulating the growth and development of paddy rice. Thus, analysis of the significance of water and the water layer on the growth and development of paddy rice and the pattern of the need for water by the paddy rice plant are important to achieving high yields of paddy rice.

I. Paddy Rice's Tolerance to Wetness

Paddy rice is different from other crops in that it must grow in a layer of water. This is a hereditary trait of the forerunner of paddy rice--undomesticated rice. The condition of submergence in water for systematic development of paddy rice has left its "brand" on the physiology of cultivated rice.

The plowing layer of the rice field, except for a very thin oxidized layer, consists mostly of a reducing layer. How does the paddy rice adapt to the condition of submersion in water? We can analyze this physiologically and by anatomy.

A. Anatonic Adaptability of the Paddy Rice Root

(1) The exodermis of the root of paddy rice is different from other crops. It has a highly lignified structure so as to prevent the reducing substances in the soil from entering the cells of the roots.

(2) The cells of the cortex of the roots of paddy rice and the cells of the cortex of the stems both disassociate themselves en masse to form intercellular spaces and connect with the organ's aerate tissue to absorb oxygen from parts of the plant above ground.

(3) The cells of the cortex of the roots are arranged in columns. According to studies by Yamasaki (1952), the intercellular space among cells arranged in columns is over two times larger than that among cells arranged obliquely in dry crops (Diagram 107), thus facilitating transportation of oxygen to the roots.

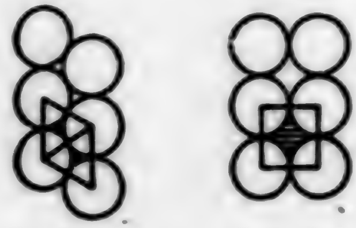

Diagram 107. Columnar Arrangement of Cells of the Paddy Rice Root (Left) Has Larger Spaces in Between Cells than Cuboidal Arrangement of Cells of Dry Crops (Right) (Slanted Lines Indicate Space in Between Cells)

B. Physiological Adaptability of Paddy Rice

1. The root of paddy rice has a strong ability of oxidation

Studies indicate the root of the paddy rice not only receives oxygen from the upper parts of the plant but also produces the strong oxidizing agent H_2O_2 from oxygen via the glycolic acid oxidation pathway. Hydrogen peroxide releases new oxygen from the effects of hydrogen peroxidase. This new oxygen has a strong oxidizing ability. Coupled with the oxygen secreted by the roots, the oxygen from these two sources form a relatively large oxidizing ring around the roots to resist damage by reducing substances and maintain the normal physiological functions of the root system.

2. Paddy rice possesses a metabolic pathway suitable to low oxygen environments and an enzymic system

Studies indicate the paddy rice plant possesses a very strong anaerobic (alcoholic fermentation) enzymic system. This system is very active especially during the beginning period of growth. Via this metabolic pathway, paddy rice can obtain a certain amount of energy under anaerobic conditions and germinate and grow under a layer of water. This characteristic can be regarded as a special adaptation to low oxygen environments which is formed during the lengthy period of systematic growth. But, the energy released by this anaerobic pathway is minimal and there is a lack of intermediate products needed in normal metabolism (such as keto acids, unsaturated acids). At the same time, the accumulation of such substances as alcohol may poison the paddy rice plant. Thus, as soon as the leaves emerge from the water surface, the paddy rice plant begins to obtain oxygen via the aerate tissues and like other dry crops will take up aerobic respiration as the major pathway. Aerobic respiration is realized via the oxidase at the tip of the plant. Under submerged and reduced conditions, the cytochrome oxidase becomes the most important oxidase at the tip of the roots in aerobic respiration. It is the special adaptive feature of the paddy rice plant in low oxygen environments because the cytochrome oxidase at the tip of the roots have a relatively large affinity for oxygen and at the same time its required level of oxygen pressure during its most active period is low (cytochrome oxidase

requires 3 percent, polyphenol oxidase requires 15 percent, xanthine proteinase requires over 50 percent).

II. Significance of Water and the Water Layer to the Growth and Development of Paddy Rice

The significance of water and the water layer to the growth and development of paddy rice is manifested in the physiological and ecological need for water by the paddy rice plant.

A. Physiological Need for Water

The physiological need for water refers mainly to the water needed directly in the normal physiological functions of the paddy rice plant and the water needed to maintain the water level inside the body of the plant. They are manifested in the following:

(1) Water is a component of the paddy rice plant and the largest component of the plant. Like other crops, water constitutes 75 percent to 85 percent of the fresh weight of the paddy rice plant and sometimes constitutes 90 percent or more. Water helps the paddy rice plant to retain its definite shape and prevent withering due to deficiency of water. This is very important since paddy rice originated from the swamp, its vacuoles are small and its mechanical tissues are developed. Water travels slowly inside the cells and tissues. Thus, the paddy rice plant is less resistant to aridity than ordinary dry crops. Under ordinary conditions, a layer of water is needed to maintain the water level inside the paddy rice plant.

(2) Water is a raw material from which organic substances are manufactured in the paddy rice plant. Water serves not only as a necessary raw material in photosynthesis but also as raw material for the synthesis of substances in material metabolism.

(3) Water serves as the major solvent of substances in the paddy rice plant and provides the environment for material metabolism. Because water has a large surface tension, its viscosity is small, and its dielectric constant is high, it is the best solvent and provides the best environment in the body of the plant for material conversion in the physiological processes of photosynthesis, respiration, transpiration, absorption and transportation. This is because in the conversion of substances, elements must first be dissolved in water before they can enter the body of the plant and move about among and inside the cells, among and inside the organs and participate in chemical reactions. When paddy rice absorbs nitrogen, phosphorus and potassium from the soil, these elements must first be dissolved in water before they are absorbed into the roots and transported along with water to the upper part of the plant above ground. These elements participate in various material metabolic activities only in the environment of water.

The physiological need for water by the paddy rice plant is a genetic characteristic of the plant's reaction to water formed during the systematic process of development. This characteristic is not affected by any temporary external condition.

B. Ecological Need for Water

The ecological need for water refers mainly to the utilization of water as an ecological factor for the creation of an external environment necessary to producing high yields. The use of water as an ecological factor is manifested in the following:

1. Use of water to regulate temperature

To assure normal growth and development of paddy rice, water is often used as a tool to regulate the microclimate in the field such as using water to retain temperatures and using water to lower temperatures. This use is related to the characteristics of water itself. The thermal capacity of water (specific heat) is high (the highest following that of liquid ammonia) and is usually designated as 1 (water absorbs 1 calorie of heat to raise 1 cubic centimeter of water 1°C). Dry soil's specific heat is 0.5 and air has a much smaller specific heat. Thus, under the same sunshine during the daytime (the same amount of heat is being absorbed), soil and atmospheric temperatures rise faster and higher than water and during the night soil and atmospheric temperatures drop faster and lower than that of water, i.e., the temperature of water is lower during the daytime and higher during the night. Thus, in production, the fields of early rice are irrigated with river water during the latter growth period in the daytime to reduce temperature and prevent the suppressive heat of high temperatures. During the latter period of late season rice the fields are irrigated with river water to raise the temperature and prevent "raised panicle heads" during the latter growth period.

The characteristic of water to reduce temperature is related to the characteristic of water requiring a large amount of heat for vaporization, the highest among all known substances on earth (1 gram of water in liquid form requires 536 calories to vaporize into a gaseous state). This characteristic produces the greatest cooling effect per unit of consumption of water and benefits water conservancy. The paddy rice plant undergoes transpiration continuously so that the temperature of the paddy rice plant remains stable within a certain range, avoiding overheating in sunshine. This is the reason why channel irrigation can reduce the temperature of the paddy rice field.

2. Use of water to regulate aeration

In the soil of the paddy rice field, water and air often exist in conflicting situations. Submerged soil contains less air and wet soil contains a lot of air. To stimulate the growth of the root system during the middle and latter period of growth when the paddy rice roots cease to emerge and grow, the broad poor and lower-middle peasants dry the fields. Then they

alternate irrigation and drying to solve this conflict of the need for both water and oxygen to stimulate development of the root system and keep the paddy rice plant green at maturity.

Under submerged conditions, an important cause affecting the development of the root system of paddy rice and the absorption of nutrients is the poisonous effect of the increasing amount of reducing substances due to a lack of oxygen. In submerged soil, atmospheric oxygen must pass through the layer of water to enter the soil. The speed of dispersion of oxygen in water is slower than the speed of dispersion in air by 10,000 times. Experiments show perpendicular permeation of water in the soil brings the oxygen of the water at the upper layer of the soil down into the lower part of the soil layer as the water flows downward. At the same time water removes the poisonous substances in the soil. Practice proves that high yielding fields are often coastal fields where permeability is high. Experiments conducted in Jiangsu Province indicated that the fields with a speed of permeation of between 9 and 15 millimeters each day and night produced the highest yield.

There are two methods to increase the amount of permeation. One method is to dig drainage trenches over 2 meters deep from the surface of the field. The other method is to place underground drainage tiles to increase the field's permeability. This method involves placing square hollow blocks or clay tiles 1 meter below the paddy rice field. Experiments conducted by the Tungxin Brigade of the Kunshan County of Jiangsu Province showed that the vitality of the root system was increased because the underground tiles enabled the water flowing in the soil to bring oxygen into the soil and remove poisonous substances (Table 136).

Table 136. Results of Increasing Activity of the Root System of Paddy Rice by Using Underground Tiles

Date of inspection	Treatment	white roots (%)	black roots (%)
August 8 (before drying the field)	with underground tile	22	6
	without underground tile	19	23
September 27 (after drying the field)	with underground tile	18	0
	without underground tile	4	45

Experimental management of underground drainage tiles during the rice planting season in Suzhou Prefecture indicates that when the field is soaked, the underground drainage tiles should be closed off and when the field is held [water withheld] the plugs to the tiles should be removed. In this way, the field's surface water can be drained in half a day and holding of the field

can be completed in 2 to 3 days. Two to three days prior to harvesting, the plugs are removed again, the water in the field is drained and the field is dried so that harvesting is facilitated and nourishment to the aging rice plants will not be hindered.

3. Use of water to regulate fertilization

Everyone knows inorganic nutrients must be dissolved in water before they are absorbed by the paddy rice plant. At the same time the water layer can heighten the absorption of nitrogen (mainly ammoniacal nitrogen), phosphorus, silicon and iron and reduce the absorption of potassium. Thus, we can regulate the moisture in the field to control the absorption of fertilizers by the paddy rice plant and direct the growth of paddy rice towards producing surplus yields. If the field is irrigated with a layer of water during the tillering period, the paddy rice plant can be stimulated to absorb nitrogen and phosphorus. This facilitates early development and "heavy application of fertilizers at the beginning." Drying the field at the end of tillering will lower the absorption of nitrogen and phosphorus by the paddy rice plant and stimulate the absorption of potassium, thus controlling ineffective tillering by the paddy rice plants and stimulating the stems to grow thick and strong. This is the reason why the poor and lower-middle peasants say "water is the switch for fertilization."

Of course, things always divide into two and "paddy rice likes water and fears water." The water layer in the rice field also presents some disadvantages. For example, long periods of submersion in water will increase the amount of reduced substances which adversely affect the growth of the root system and at the same time allow fertilizers to drain away. These problems should be taken into consideration.

The physiological need for water by the paddy rice plant and the ecological need for water by the colony under ordinary conditions are uniform. Management of irrigation and muddiness in the field is based on this uniform relationship. Only under special conditions when the physiological need for water by the individual plant and the ecological need for water by the colony are in conflict (such as when the paddy rice plant grows too prosperously), is the method of management of irrigation and muddiness of the field determined by the ecological need for water of the colony. Since the physiological need for water of the paddy rice plant and the ecological need for water both have definite ranges of change, and coupled with the complex factors involved in agricultural production, the methods of management of irrigation and muddiness of the field is manifold. Without taking into consideration the actual natural conditions and conditions of cultivation, a reasonable method of management of irrigation and muddiness of the field cannot be established. However, the water layer and irrigation methods to keep the paddy rice very damp are determined by the genetic characteristics of paddy rice and are common to all methods of management of irrigation and muddiness of the field. All other methods of management are based on this common characteristic and are developed and differentiated from the ecological need for water.

III. Patterns of Paddy Rice's Need for Water and Principles of Control of Water and Muddiness

A. Patterns of Paddy Rice's Need for Water and the Root System's Absorption of Water

1. The amount of water needed and the amount of water consumed by paddy rice

The amount of water needed by a crop to produce a unit of dry substance is called the unit amount of water needed (also called the transpiration coefficient). The unit amount of water needed is generally between 400 and 700, i.e., between 400 and 700 jin of water are needed to produce 1 jin of dry substance. The unit amount of water needed by paddy rice varies according to the different growth periods and changes in external environmental conditions.

The actual amount of water consumed in the field is also known in agricultural terminology as the amount of water needed, but this has a different meaning. The actual amount of water consumed in the field includes the amount of water lost in transpiration and the amount of leakage in the field and evaporation from plants in the holes, generally expressed in millimeters. Concerned units have determined the amount of water consumed in the paddy rice field in the middle and lower reaches of the Chang Jiang for early rice to be between 300 and 570 millimeters and between 380 and 700 millimeters for late season rice (Table 137).

Table 137. Amount of Water Required by Double Season Rice in Rice Fields South of the Chang Jiang

(a)	(b)	(c)	(d)		(f)		(g)
			(e)	%	(e)	%	
(h)	160~260	110~210	270~470	67~82.6	30~100	17.4~33	300~570
(i)	210~300	140~240	360~540	77~92	30~100	9~23	380~[illegible]

Key:
(a) type of rice
(b) amount of evaporation (mm)
(c) amount of transpirtation (mm)
(d) Amount of evaporation and transpiration
(e) millimeter
(f) amount of leakage
(g) total amount of water required (millimeter)
(h) Early rice
(i) Late season rice

In general, the greatest amount of water consumed per day is during the heading and flowering periods but in actuality the timing may be earlier or later to a varying degree depending upon weather conditions at the time. As Diagram 108 shows, the greatest amount of water consumed per day by early rice is during the flowering period while the greatest amount of water consumed per day by late season rice is during the panicle bearing period.

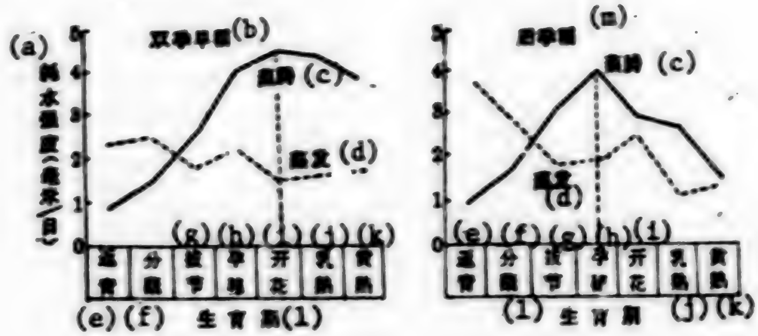

Diagram 108. Changes in Daily Water Consumption During Each Growth Period of Double Season Rice (From "Cultivation of Paddy Rice in China")

Key: (a) intensity of water consumption (mm/day)
(b) Double season rice
(c) Transpiration
(d) Evaporation
(e) Greening
(f) Tillering
(g) jointing .
(h) panicle bearing
(i) flowering
(j) milky ripe
(k) yellow ripe
(l) growth periods
(m) late season rice

2. Absorption of water by the root system of paddy rice

The major organ of the paddy rice plant that absorbs water is the root system (root hairs). The power to absorb water is mainly due to the root's osmotic pressure and the pull of transpiration.

(1) The root's osmotic pressure: On warm and damp mornings, transpiration weakens and a drop of water appears on the tip of the leaf. This drop of water is not dew but water emerging from the pores of the tip of the leaf. This phenomenon is called "emitting water."

In addition, when we cut the surface of the stem of paddy rice near the surface of the soil, sap emerges from the cut. This is called "bleeding." The sap that flows out is called the bleeding sap. If a rubber tube is attached at the cut and connected to a pressure gauge, the mercury in the pressure gauge will rise. The pressure causing the bleeding sap to rise in the ducts inside the plant due to the physiological activity of the root system is called the pressure of the root.

The composition of the sap from "bleeding" or from "emission" is complex. It contains such organic substances as sugars and amino acids as well as inorganic salts and water. For example, the bleeding sap from the paddy rice plant contains 18 kinds of amino acids.

"Emission" and "bleeding" phenomena of the paddy rice plant show that pressure of the root exists in the paddy rice plant. Experiments indicate when

the root is treated with ether or chloroform, the phenomenon of water emission immediately ceases. When the plant's respiration is suppressed, bleeding reduces or stops. Thus, exertion of pressure by the root is a process closely related to physiological activity. The absorption of water related to the life activity of the root system is called the active absorption of water.

Emission of water by the paddy rice plant is important in production. Experienced farmers can judge the strength of the activity of the root system by observing the amount of water emitted. This amount of emitted water can serve as a physiological indicator of greening of the paddy rice plant. Prior to flowering, paddy rice plants that emit a large amount of water in sunny and clear weather often fill their grains rapidly.

(2) Transpiration: Transpiration is the evaporation of moisture in a gaseous state from the surface of the stem and leaves after water has been absorbed into the body of the plant by the roots. It is generally believed that transpiration can stimulate the absorption of inorganic elements. When transpiration of the paddy rice plant is strong, there is a deficiency of water in the paddy rice plant and the cells are not saturated by moisture. Thus, the leaves have a strong absorptive strength. This absorptive strength is transmitted through many mechanical tissues to the root system so that the cells of the root system are in an unsaturated state causing the roots to absorb water. Experiments show if the roots of the paddy rice plant are removed and the stem is placed in water, transpiration can still be maintained and water is still absorbed by the plant. Thus, the strength of absorption of water of the root system is due to the pulling strength of transpiration called the pull of transpiration. The absorption of water due to the pull of transpiration is passive and is thus called "passive absorption of water."

Factors that affect absorption of water by the root system of the paddy rice plant and factors affecting the root system's respiration are closely related. For example, low temperatures reduce the root system's respiration and thus reduce the absorption of water. Again for example, if carbon dioxide is supplied to the roots of the paddy rice plant, the strength of absorption of water will quickly drop, but when the roots are supplied with air, respiration of the roots intensifies and the absorption of water intensifies. Thus, management of irrigation and muddiness of the soil should follow the pattern of the need for water by the paddy rice plant. During certain stages of growth, the field should be alternately irrigated. This stimulates the absorption of water by the paddy rice plant.

In addition, concentration of the solutions in the soil also affects the absorption of water greatly. If the concentration of the solutions in the soil is higher than the osmotic pressure of the cells of the root system, the root system will not be able to absorb water, will wither and die. Thus, in newly developed seashore fields, if the concentration of salt is too high, the field must first be irrigated to wash away the salt.

3. Critical period of moisture in the paddy rice plant

Paddy rice is like other crops, its tolerance to aridity changes as the individual plant develops. The period in which the plant becomes most sensitive to a deficiency of water is the period in which the most serious damage is caused by drought. This period is called the critical period for moisture in the plant. The paddy rice plant generally has two critical periods for moisture: one is the panicle bearing period and the other is the period between flowering and filling. Drought occurring during these two periods will cause the most reduction in yield.

The panicle bearing period, described more accurately, is the period between the time the quadruplet of the pollen mother cell divides and the time pollen grain is formed. The plant is most sensitive to aridity during this period. Drought damage is manifested by damage to the reproductive organs, especially the abnormal development of the pollen causing sterility and deformed and degenerate spikelets. When the plant is damaged by drought during the flowering period, pollination and fertilization are affected and empty grains are formed. When seriously affected, the entire panicle wilts, dries up and becomes a white panicle. Damage by drought during the milky ripe stage is also relatively serious. Damage is done mainly to the filling of the seed grain. There is formation of semi-filled grains and the 1000 grain weight drops.

Damage by drought is due physiologically to a deficiency of water which causes withering, a reduction of photosynthesis, intensification of metabolic decomposition, suppression of metabolic synthesis (of protein, nucleic acids, starch) and destruction of oxidation and phosphatization which produce energy, thus suppressing the process of growth.

A comparison of the tolerance to drought during the vegetative growth period and the reproductive growth period shows that the paddy rice plant is less tolerant to drought during the reproductive growth period and damage by drought during this period is more serious. Since the paddy rice plant is more tolerant to drought during the latter period of tillering, this is a good time to dry the paddy rice field.

B. Principles of Control of Water and Muddiness in Paddy Rice Cultivation

Water is the "master switch" for fertilizers and also the "regulator" of air and temperature in the soil. Thus, water directly stimulates and controls the growth of paddy rice. Good management of irrigation and muddiness of the field is important in realizing high yields of paddy rice. Throughout the entire life of the paddy rice plant, the need for water is absolute and hereditary. But in particular stages of growth, the need for water is relative. The physiological bases for the management of irrigation and muddiness of the field are discussed in the following, taking into consideration the characteristics of each growth stage and the relationship between physiological need and ecological need for water according to the pattern of the need for water by the paddy rice plant.

1. Wet irrigation prior to the three leaves stage

The period from germination of the seed to the time prior to emergence of the third leaf is the period in which the roots root, the leaves leaf and the seedlings form strong sprouts. Physiologically, the stored substances in the endosperm are fully utilized and converted for use in building new organs so that the seedling can rapidly change from a basically heterotrophic metabolic into an autotrophic metabolic type of growth.

During this stage, the young seedling possesses an anaerobic respiratory pathway adapted to low oxygen environments and the plumule can utilize the small amount of energy released by this pathway to grow. However, submerged conditions will adversely affect the growth of the roots because the aerate tissue of the young seedling has not been formed completely and the conversion of stored materials in the endosperm (material conversion and energy conversion) is greatly reduced. This adversely affects cultivation of strong and healthy seedlings and lowers the plant's resistance to adverse external environmental conditions causing the seedlings to die and rot. It has been determined that when the water content in the soil reaches 70 percent to 80 percent of the maximum amount of water retained by the soil, the accumulation of dry substances in the seedling remains mostly in the roots and the leaves. The roots constitute between 40 percent and 50 percent of the total dry weight of the plant and the leaves constitute between 35 percent and 45 percent of the total dry weight while the plumule sheaths constitute only 5 percent to 10 percent of the total dry weight. Under irrigated conditions in which the soil is covered by a layer of water, the situation is the opposite. The plumule sheaths constitute between 50 percent and 60 percent of the total dry weight, the leaves constitute between 30 percent and 40 percent and the young roots constitute only 5 percent to 10 percent. Thus, during this period, the most suitable moisture condition under ordinary conditions is when the soil's moisture content is about 70 percent to 80 percent the maximum capacity of water retained in the soil. This condition exists when the trenches are filled with water but the seedbed surface is dry and the soil layer is wet. Of course, under low temperatures and during a drought (dry air), water must be used to retain the temperature in the field. Likewise the dampness of the field must be increased because of such changes in the major elements.

The above analysis indicates the appropriate amount of moisture between germination and the third leaf stage is actually the result of a proper combination of water and oxygen. The moisture condition controls the content of oxygen and the effective conversion and utilization of nutrients and energy. Thus, it controls the healthy growth of such organs as the roots and the leaves. Therefore, damp irrigation is the most suitable method of irrigation during the period prior to the third leaf stage and is the physiological basis for dry cultivation of seedlings for short seedling ages. The paddy rice plant can skillfully utilize water to activate its own physiological activities when it possesses a definite root system and functioning leaves and when it is able to live in water. This occurs in the period after the third leaf stage.

2. Shallow water and frequent irrigation during the tillering period

After the third leaf stage, the physiological characteristics of the young seedling of paddy rice and the demand for moisture change and manifest themselves in the following:

(1) The aerate tissue system in the plant body is fully grown and photosynthesis gradually strengthens (photosynthesis releases oxygen and transports oxygen to the roots for respiration). The plant improves its adaptation to low oxygen conditions in shape and physiologically.

(2) As the leaves and tillers grow, the area of transpiration increases and as the temperatures rise the physiological and ecological need for water increases daily.

(3) After the seedling changes to autotrophic growth, nutrients from the soil provided by the root system and nutrients in the air provided by the leaves (photosynthesis) became the sources of nutrients for the plant. The layer of water facilitates the absorption and utilization of the soil's nutrients.

Thus, moisture conditions required by the plant at this stage are different from those during the third leaf stage. Production practices and experiments conducted by related units indicate shallow water and frequent irrigation is the most suitable method of irrigation during this period (Table 138). In particular, when the plant begins to tiller after the fourth leaf period, the healthy or poor growth of the leaves on the main stem directly affects the emergence and growth of the tillers. Experiments have shown the growth of the leaves on the main stem is directly related to the moisture content in the leaves. When the field is irrigated by a shallow layer of water and the water content in the leaves reaches 78.3 percent, tillering is encouraged. In damp conditions, the water content of the leaves is only 72.6 percent. This reduction in the water content is due mainly to the reduction of free water in the cells (free water/bonded water, 0.55 for the former and 0.32 for the latter). Free water is the medium in which enzymes stimulate biochemical reactions and physiological activities which are carried out within the cells. A drop in the amount of free water will necessarily bring about a reduction in the amount of leaf growth. This adversely affects the emergence of tillers.

Table 138. Effect of Moisture in the Soil Upon Dry Weight of Paddy Rice Plant (100 plant dry weight: gram)

水分状况 (a)	(b) 幼苗期				(c) 分蘖初期
	第一叶 (d)	第二叶 (e)	第三叶 (f)	第四叶 (g)	
(h) 湿润	0.66	1.56	3.61	5.73	19.6
(i) 淹水1厘米	0.29	1.09	4.12		25.4
(j) 淹水3厘米	0.29	0.65	1.66	7.45	30.7

[Key on following page]

[Key to table on preceding page]

Key: (a) moisture condition
(b) young seedling period
(c) beginning tillering period
(d) first leaf
(e) second leaf
(f) third leaf
(g) fourth leaf
(h) wet
(i) water layer of 1 centimeter
(j) water layer of 2 centimeters

It must be pointed out also that in highly fertile paddy rice fields the methods of alternating dryness and dampness, damp irrigation and even dehydration of the field for short periods are used during the tillering period. These methods are mainly determined by the ecological need for water and have their physiological basis. Studies indicate that under ordinary conditions, when the water content of the soil at the tillering nodes drops to 70 percent or to 80 percent of the saturation, the growth of the leaves and tillers on the part of the plant above ground will have already been visibly suppressed but the intensity of photosynthesis and the level of metabolism will not have been visibly reduced. In the leaves, transportation and utilization of nutrients are hindered while carbohydrates accumulate in the leaves. When the plants are reirrigated, these accumulated nutrients will be concentrated for use for the growth of new organs. Thus, under sufficient fertilization, growth can quickly catch up with that of paddy rice cultivated in a layer of water. Thus, where the soil is overly fertile, drainage is poor and the rice seedlings grow too much, damp irrigation can control the overly extensive growth immediately and also stimulate growth as an aftereffect. Although this method of management of irrigation and muddiness in the field does not respond to the physiological need for water of the individual plant, it is a reasonable method in responding to the ecological need for water by the colony.

3. Drying the field and its physiological significance during the end of tillering

The final period of tillering is the transition period from vegetative growth into reproductive growth. During this period the relationship among the individual plant and the colony and between organ and organ is complex. At this time, the colony is in the peak tillering period and the competition for light and fertilizers is keen. The individual plant must grow new vegetative and reproductive organs and the part of the plant above ground as well as the part underground must grow all at the same time. On the upper part of the plant above ground, the leaves and the stems must grow, the young panicles must differentiate and the tillers must differentiate towards two extremes. To regulate the growth of the organs and solve the conflict between the growth of strong stems and large panicles, the field at this time as a general practice, is drained and dried (baking the field, holding the field) according to the tolerance to aridity of the paddy rice during this period.

The physiological significance of drying the field can be understood in the following aspects:

(1) Control of ineffective tillers, solidification of effective tillers and raising the percentage of formation of panicles from tillers: Drying the field at the final period of tillering causes a temporary deficiency of water in the paddy rice field. Since the root systems of young and small tillers at higher positions are not fully developed and the cells are not tolerant to dehydration because of a low concentration of fluids, these small tillers are more easily affected by aridity than the main stem or the large tillers at lower positions. Thus, they die. During the dying process, parts of the nutrients flow back to the main stem and are absorbed and utilized by the large tillers. This benefits solidification of effective tillers, raises the percentage of formation of panicles and establishes a good structure of the colony in the large field.

(2) Improvement of the soil environment and strengthening of the activity of the root system: Because of the lengthy period of submersion under water, the soil is strongly reducing during the tillering period and the electrical potential of oxidation reduction is low. This adversely affects the growth of the root system. By drying the field, the content of oxygen in the soil increases and favorable conditions are created to dissolve reduced substances that are poisonous and to eliminate mineralization of organic substances (increasing the amount of effective nutrients) (Tables 139, 140).

Table 139. Changes in Soil Environment Before and After Drying the Field (Former Pedology Institute, Chinese Academy of Sciences, 1961)

(a) 测定日期		水层状况	(e) 渗透水中气体含量		氧化还原电位
月/日 (b)	(c) 处理前后天数	(d)	CO_2 毫克/升 (f)	O_2 毫克/升 (f)	(毫伏) (g)
8/29	烤田前5天 (h)	水层 (d)	76.5	1.64	190
8/7	烤田后5天 (i)	烤田 (l)	53.2	1.74	170
8/15	复水后1天 (j)	水层 (d)	18.6	3.40	365
8/17	复水后3天 (k)	水层 (d)	41.6	1.71	280

Key:
(a) Dates of measurements
(b) month/day
(c) number of days before and after treatment
(d) water layer
(e) content of gases in permeated water
(f) milligram/liter
(g) electrical potential of oxidation reduction (millivolt)
(h) 5 days before drying the field
(i) 5 days after drying the field
(j) 1 day after reirrigation
(k) 3 days after reirrigation
(l) dry field

In addition, through drying the field and following the improvement in soil conditions, the activity and function of the root system are stimulated. These are manifested in the following:

First, by neutralizing the poisonous effects of such reduced substances as hydrogen sulphide, the number of black roots decreases and the number of white roots increases (Table 141).

Table 140. Effect of Drying the Field of Early Rice Upon Content of Fertilizers and the Soil's Reduced Substances (milligram/100 grams ±) (Yan Qinquan (0917 2953 3123)

测定日期 (a)	活性还原物质 (b)		亚铁 (c)		硝态氮 (d)		有效磷 (e)	
	晒田 (f)	不晒田 (g)	晒田 (f)	不晒田 (g)	晒田 (f)	对照 (g)	晒田 (f)	对照 (g)
5/22(晒前) (h)	10.01	7.67	100.02	76.49	6.83	3.78	1.88	1.1
6/2 (晒终) (i)	1.84	5.91	5.97	90.3	1.00	3.16	0.66	0.83
6/9 (复水后) (j)	1.91	5.10	2.76	75.16	0.80	6.01	1.64	1.84

Key: (a) dates of measurements
(b) active reduced substances
(c) ferrite
(d) nitrate nitrogen
(e) effective phosphorus
(f) drying the field
(g) not drying the field
(h) 5/22 (before drying the field)
(i) 6/2 (end of drying the field)
(j) 6/9 (re-irrigated

Table 141. Effect of Drying the Field Upon the Roots of Three Different Colors (Former Pedology Institute of the Chinese Academy of Sciences, 1961)

处理 (a)	每株平均根数 (b)	白根 (%) (c)	黄根 (%) (d)	黑根 (%) (e)
晒(f)田	97.0	8.4	83.0	8.6
对(g)照	93.6	2.2	61.6	36.3

Key: (a) treatment
(b) average number of roots per plant
(c) white roots
(d) yellow roots
(e) black roots
(f) drying the field
(g) control

Second, the respiration of the root system intensifies. Wang Wanli [3769 8001 6849] et al (1960) showed in their studies that when the field is dried, the moisture on the surface soil reduces in content, the root system at the surface layer dies and the amount of bleeding from the paddy rice plant reduces. After re-irrigation, the soil environment improves, the respiration of the root system intensifies, the activity of the root system strengthens and the area of activity of the root system expands. (Diagram 109).

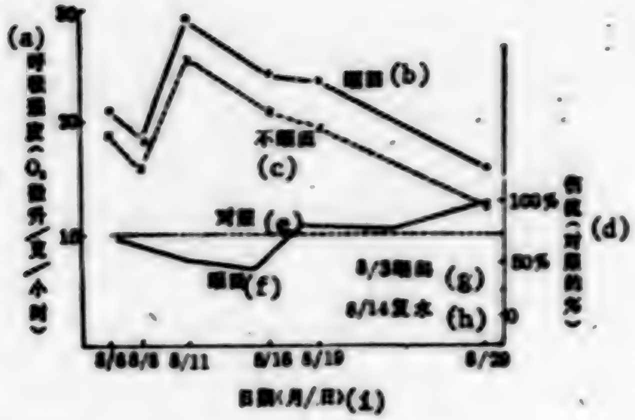

Diagram 109. Effect of Drying the Field Upon Intensity of Respiration of Paddy Rice and Damaging Loss

Key:
(a) intensity of respiration (O_2 microliter/gram/hour)
(b) drying the field
(c) not drying the field
(d) damaging loss (% of control)
(e) control
(f) drying the field
(g) 8/3 field dried
(h) 8/14 re-irrigated
(i) date (month/day)

Third, when the field is dried, the activity of the root system temporarily slows. The amount of effective phosphorus and nitrogen in the soil lessens, the amount of nitrogen and phosphorus absorbed by the paddy rice plant is less. After re-irrigation, the activity of the root system intensifies and the absorption of potassium visibly increases. Since potassium helps to strengthen lignification of the thick walled cells of the stem, thicken the walls of the stem and develop vascular bundles, it serves to prevent the plant from lodging.

(3) Material metabolism in the plant is advantageous to changes in reproductive growth. After drying the field, the soil's content of nitrogen and phosphorus is reduced and the growth of the plant is suppressed, affecting the intensity and direction of material metabolism within the body of the plant. Drying the field lowers the level of nitrogen metabolism (synthesis of proteins) and raises the metabolism of carbon, thus stimulating the accumulation of carbohydrates (Diagram 110). At the same time, drying the field stimulates transportation of more carbohydrates to the leaf sheaths and the developing stems. This is favorable to filling and strengthening the stem's resistance to breakage.

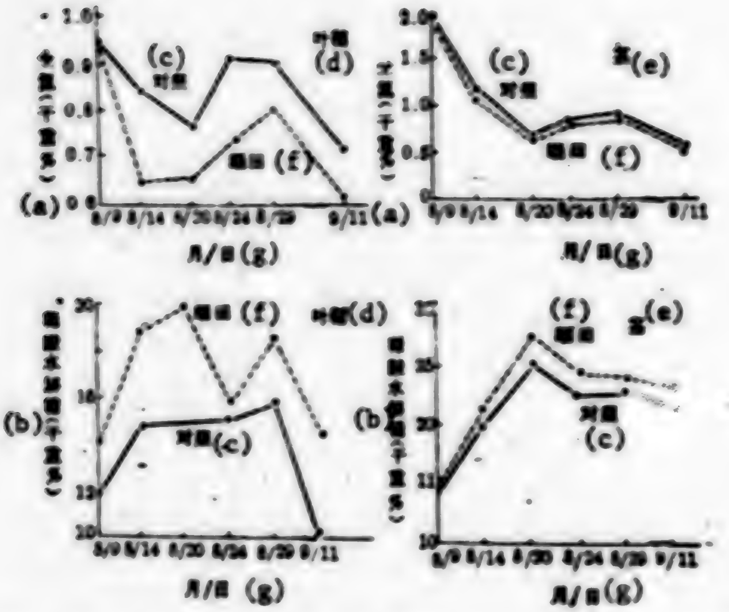

Diagram 110. Effect of Drying the Field Upon Content of Nitrogen and Carbon in Paddy Rice (Wang Wanli (3769 8001 6849) et al, 1965)

Key: (a) total nitrogen (dry weight %)
(b) dilute acid and hydrolized sugar (dry weight %)
(c) control
(d) leaf sheath
(e) stem
(f) drying the field
(g) month/day

Drying the field during final period of tillering stimulates the accumulation of carbohydrates in the stem and sheaths. This is beneficial to the growth of strong stems, strengthens resistance to lodging and helps the formation of large panicles. Studies indicate that during the early period of young panicle differentiation, the content of carbohydrates (mainly starch and sucrose) in the stem and sheath reduces while the content of carbohydrates in the young panicles increases. Drying the field once stimulates the accumulation of carbohydrates in the stem and the sheaths. After re-irrigation the amount of accumulated carbohydrates being transported to the young panicles quickly increases. This change provides more sources of nutrients during the beginning period of young panicle differentiation. After the field is re-irrigated, the activity of the root system also intensifies and nutrients are continuously being supplied to the developing young panicle. The proper combination of control and stimulation and the manifestation of "blackening, yellowing and blackening" of the leaves may be the physiological basis for drying the field and the basis for formation of large panicles. It must be pointed out that the desired result can be achieved by the correct use of the technique of drying the field. A key link is the degree of drying. Studies indicate increased

yields are possible when the accumulation of soluble carbohydrates in the leaves during the period of drying remains higher than average after the field is re-irrigated. A reduction in yield will result if the accumulation of soluble carbohydrates during the period of drying the field increases rapidly but drops drastically below the average after the field is re-irrigated. The reason is because drying the field too much destroys metabolism and adversely affects formation of yield. A requirement established by the Dongting Brigade of Wuxi County, Jiangsu Province, for drying the field is "to hold the entire field until the soil wrinkles (dried so that the surface of the soil splits and thin wrinkles emerge) but the surface of the soil does not appear white," and "white roots (free roots) emerge, the leaves are erect, the color of the leaves lightens and the leaves grow steadily and with strength." These are morphological changes in the plant and the soil that indicate the degree to dry the field.

It must be pointed out also that since the growth characteristics of early and late rice are different, there is a difference in drying the fields for these two types of rice. It has been mentioned before that late rice is characterized by "separated" growth, i.e., during the latter period of tillering, the first internode begins to elongate and young panicles begin to differentiate only when the second internode has begun to elongate. This characteristic provides a favorable condition for drying the field. We can dry the field at the end of tillering and at the beginning of jointing to stimulate growth of the roots so that the paddy rice plant will "yellow once," growth of the nodes is halted temporarily and death of ineffective tillers is hastened. The field is then re-irrigated to stimulate thickening of the stem and to hasten the growth of effective tillers. The plant will "blacken a second time." All of these provide necessary material bases for the formation of strong stems and large panicles. The procedure is different for early rice, which is characterized by "overlapping" growth (late season rice is also characterized by a similar type of "overlapping" growth), i.e., before tillering ends, the young panicles begin to differentiate but jointing occurs during the spikelet differentiation period. This growth characteristic poses a definite difficulty for drying the field. If the field is dried too early during the period of tillering, the formation of effective tillers will be adversely affected and strong stems will not be able to form. If the field is dried late, young panicles will be affected and formation of large panicles will be adversely affected. Stimulating early rice to germinate early is a way to solve this conflict. When the plant has germinated early, the number of panicles is assured and the field can be dried when tillering is approaching its end and young panicle differentiation has begun only for a short while. In this way, an abundance of panicles and large panicles can be realized and the stems will grow strong. If the growth of early rice during the early period is insufficient and the number of panicles is insufficient, the field can only be lightly dried after panicle differentiation. After the field is re-irrigated, fertilizers for panicle growth should be applied to stimulate growth of more and large panicles.

4. Shallow and frequent irrigation during the period from panicle differentiation to heading

The period from panicle differentiation to heading is a period in which the organs of the panicles are formed. It is also the peak period in the life of the paddy rice plant which requires the most amount of water physiologically. The amount of water required during this period constitutes about 40 percent of the total amount of water needed throughout the life of the plant. Under ordinary conditions, the field should be shallowly and frequently irrigated. The significance of this is as follows:

(1) To protect young panicles: During this period, the young panicles are the most tender organs of the rice plant. They contain a rich storage of protoplasm, their metabolism is intense and their content of water is abundant. If there is a deficiency of water during this period, the tender organs will have to absorb water. This damages the developing young panicles and hinders growth. If the deficiency of water occurs during the early period of young panicle differentiation, the differentiation of the spikelets and the secondary branches will be suppressed. If the deficiency of water occurs during the latter period of young panicle differentiation, mitosis will be hindered, resulting in small panicles and an increase in unfilled grains.

(2) To assure the flow of material: When the paddy rice plant develops to this stage, different organs begin to perform different functions and a center for material manufacturing (the leaves), a center for storage of material (stem, leaf sheaths) and a center for conversion and synthesis (panicles) emerge within the plant. Synthesis of organic substances of carbon and nitrogen occurs mainly in the leaves. The substances are stored mainly in the stem and the leaf sheath and converted and resynthesized in the young panicles. Physiologically speaking, there must be a definite supply of nitrogen during this period as well as a sufficient accumulation of carbohydrates and a smooth flow of such substances to the panicles for the formation of large panicles. Shallow and frequent irrigation provides a moisture condition that assures such functions.

Observation indicates that after the young panicles have grown to a length of between 1 and 2 centimeters, the speed of growth increases linearly. The intensity of prosperous growth depends upon the corresponding supply of materials that establishes the form of the paddy rice plant. Formation of these substances depends upon the coordination of the functions of the leaves, leaf sheaths, stems and roots. In other words, the leaves must have strong capabilities to synthesis organic matter, the root system must be able to actively absorb nutrients and these organic materials must be smoothly transported from the leaves to the leaf sheaths, stems and panicles. Experiments show that during panicle differentiation, especially during the period of panicle extension, draining and drying the field will lessen the opening of the stomates because of the deficiency of water and entry of carbon dioxide into the cells will be hindered, easily causing a reduction of photosynthetic intensity. Even after the field is re-irrigated, it will take over one week for the plant to return to normal growth. Under this condition, transportation of organic matter to the panicles is also affected. A deficiency of

water lowers the degree of dissolution of nutritional elements of the soil's nutrients. In particular, nitrogen easily oxidizes to become nitrate nitrogen which is not easily absorbed and utilized by paddy rice. All of these factors often cause degeneration of the spikelets and increase the number of unfilled grains.

(3) Use of water to regulate temperature: During the period of differentiation and development of young panicles, especially during the period of mitosis, a high soil temperature of above 40°C (such as for intermediate rice) or a soil temperature below 15°C (such as for late season rice) will often cause massive degeneration of spikelets. Experiments show the use of water to reduce high temperatures and deep irrigation to retain temperatures during low temperature periods will effectively reduce sterility and degeneration. Thus, from the point of view of the ecological need for water, the field needs to be irrigated by a layer of water during this period.

5. Running water irrigation during the heading and maturation periods and management of irrigation and muddiness of the field by "alternating dryness and wetness while taking wetness as the key"

After heading, the paddy rice plant flowers, undergoes fertilization and begins to fill its grains. The major problems during this period are to increase the weight of the grains and to prevent early withering of the leaves. These problems are solved by running water irrigation and "alternating dryness and wetness while taking wetness as the key" in managing irrigation and muddiness of the field. The reasons are:

(1) During the latter period of growth of paddy rice, the distance which oxygen has to be transported from the leaves to the roots has extended and the aerate tissues of the upper part of the nodes of the stem are not as developed as before. In some varieties, there is no differentiation of aerate tissues above the fourth internode counting from the base of the plant. Thus, a deficiency of oxygen in the root system easily occurs. In addition, active new roots do not emerge after jointing, thus it is necessary to alternate dryness and wetness to maintain the physiological functions of the old roots.

(2) Running water irrigation is not only favorable to maintaining the activity of and extending the photosynthetic function of the leaves but also stimulates transportation of photosynthetic products to the grains which in turn facilitates filling and increasing the weight of the grains. At this time the roots of the paddy rice plant have begun to weaken and their activity has reduced. Organic substances of carbon and nitrogen for filling the grains enter the seed grains almost strictly according to percentage. Thus, if the root system withers early, the supply of nitrogen will be deficient and the nitrogen that enters the grains will have to come from the leaves. This causes the leaves to wither early. In addition, and as mentioned before, the root system also synthesizes amino acids and certain physiologically active substances (such as cytokinins) to maintain the activity of the leaves.

The above causes indicate that the leaves can be retained only if the roots are nourished and nourishing the roots requires providing the soil with oxygen. Thus, in practice, live water irrigation and "alternating dryness and wetness and taking wetness as the key" is the only way of using water to retain fertilizers in the soil and provide oxygen to the roots. In this way the roots will be able to maintain the life of the leaves, the plant will be able to ripen while still green and the grains can be fully filled.

6. Principles of management of irrigation and muddiness of the field of hybrid paddy rice

To fully develop heterosis of hybrid paddy rice, management of irrigation and muddiness of the field is an important link.

Management of irrigation and muddiness of the field of hybrid paddy rice during the early and late periods of growth is basically the same as that for ordinary paddy rice. However, since hybrid paddy rice depends upon formation of large panicles from tillers to produce high yields, it is more sensitive to water during the young panicle differentiation period. Spikelet and branch degeneration caused by conditions of drought must be prevented. Thus, it is important to grasp the middle period of growth for drying the field and the degree of dryness during this period. In general, a field with 30,000 to 40,000 basic seedlings per mu should be dried when the number of tillers from the main stems reaches 200,000 to 250,000. Because the root system of hybrid rice is developed, the degree of drying of the field is determined by the conditions of growth. Fields in which growth is normal require only light drying while fields in which growth is prosperous must be dried heavily so that the color of the leaves will lighten and free roots will expose themselves on the surface of the soil. The sides of the fields should be opened slightly.

In general, reasonable management of irrigation and muddiness of the field is based upon satisfying the rice plant's physiological need for water. It's purpose is to unify synthesis, transportation, conversion, storage and distribution of materials inside the body of the rice plant and to achieve high yields by developing the ecological functions of irrigation and water. Techniques of cultivation have been established according to man's understanding of the nature of paddy rice, environmental conditions and practical demands to produce high yields.

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CHAPTER 10. JUDGING GROWTH AND CONDITION OF THE PADDY RICE PLANT BY OBSERVING THE SEEDLING

During the growth process of paddy rice, mutual functions of inner causes and external conditions follow a pattern of material, energy, and morphological conversions. Morphological conversions can be directly observed and have long been taken by man as the bases for judging whether the growth and development of the paddy rice plant are normal or not. But morphological changes often are affected greatly by external factors and frequently several external conditions will bring about similar or closely related morphological changes. Thus, when judging the growth and condition of the paddy rice plant by observing the seedlings in the field, biochemical or biophysiological inspections must be made at the same time to discover the true causes of abnormal changes. This is so that effective cultivation measures can be taken to direct the growth of the paddy rice plant toward producing high yields and improving the quality of the paddy rice plant. These constitute the content and purpose for judging the growth and condition of the paddy rice plant by observing the seedlings.

I. Basis for Judging the Plant's Condition by Observing the Seedling

A. Color of the Root

The color of the root is an indicator which can be easily observed and diagnosed. The colors of the root include white (milky white or grayish white), yellow (yellowish brown or rusty red) and black. These colors reflect the physiological vitality of the root system and the conditions of the soil (aeration, content of chemical substances and content of microorganisms) and serve as important bases for judging the seedlings. Tender seedlings have short roots which are often shorter than 10 centimeters. There are no branching roots at the base. The roots appear milky white and are resilient. Roots that appear grayish white, do not possess resilience and become white and rotting have been damaged by poisonous organic acids or infected by microorganisms (rotting mildew).

Because paddy rice is a marsh plant, the root system has the capability to secrete oxygen and can oxidize the reduced substances surrounding the root. This is called oxidation by the roots. The strengthe of oxidation of the tip of the roots is strong. Oxygen spreads into the surrounding areas of the roots extending a distance of several millimeters and oxidizes the bivalent ions of iron into trivalent ions of iron which settle in the soil.

This is the reason for the appearance of a reddish brown colored ferric oxide layer at a distance from the tip of the root or new roots while the areas near the tip of the roots still remain milky white. As the roots extend, the oxidation strength of the cells of the base of the roots reduces, the ferric oxide layer gradually approaches the roots and finally it covers the surface of the roots forming a rusty film (ferric oxide film). The roots become yellowish brown or even rusty red. These roots are called in general "yellow roots." Formation of the rusty film reflects the abundance of bivalent ions of iron in the soil and is an indication of reduced vitality of the roots. The film serves to protect the roots and to reduce the poisonous effects of such reduced substances as hydrogen sulphide so that the roots can still absorb fertilizers by ionic exchange. Different types of yellow roots can be differentiated from the darkness or lightness of the yellow color, the proportion of the yellow part as a percentage of the total length of the root and the number of branching roots at the base of the stem. Roots longer than 10 centimeters which are called "extended roots" are those that have emerged about one leafing cycle (5 to 7 days) ago. If branch roots have emerged from the base and appear yellowish brown while the tip of the root small remains milky white, then the plant is growing normally. If there are no branch roots at the base and most of the roots have turned yellow and even the tip of the roots is yellow, then the roots have yellowed and have become stunted. At this time a layer of rusty water or rusty spots can be seen on the surface of the field.

When the soil of the paddy rice field is deficient in oxygen, hydrogen sulphide is formed. When the soil contains a relatively high content of iron, black ferric sulphide is formed. This hinders movement of hydrogen sulphide. If the soil contains less amounts of iron or when too much hydrogen sulphide has formed in the soil, then the excess hydrogen sulphide will move towards the roots and combine chemically with the rusty film on the root surface, forming "black roots." Black roots indicate further weakening of the activity of the root system. It has been determined that the black substance that begins to form is ferric sulphide. At this time, only part of the roots becomes black. The black substance does not dirty the hands when the roots are uprooted and there is no repugnant smell. There is only a slight blackening of the roots. The black substances that form later on is ferrous sulphide. Now, most of the roots are black and the black substance dirties the hands when the roots are uprooted. There is a repugnant odor. Ferrous sulphide prevents hydrogen sulphide from entering the roots to a certain extent and thus the inner tissues of the roots have not rotted. This constitutes serious blackening of the roots. When these two kinds of roots are placed in a 0.002 percent to 0.01 percent solution of lime water, the color of the slightly blackened roots will become lighter while the color of the seriously blackened roots will not change. When hydrogen sulphide enters the inner tissues, "black root heads" can often be seen. The roots have been seriously poisoned. This belongs to the rotting type of black roots. The three types of black roots described above are three stages of one single process and often they may occur in the same field alternately.

B. Color Changes of Leaves

Leaves are the major organs of photosynthesis. The lightness or darkness of the color of the leaves often reflects the intensity of photosynthesis of the plant. When the color of the leaves is "black," nitrogen metabolism is prosperous and new organs grow abundantly. This is called expansive metabolism. When the leaves are yellow, nitrogen metabolism is weak, carbon metabolism increases and the amount of starch stored in the leaf sheaths increases. This is called cumulative metabolism. The growth of tillers, stems, panicles and grains follow a definite temporal pattern. Photosynthetic products of the leaves often are distributed on a priority basis to the growth center at the moment. Those parts of the plants receiving an insufficient supply of nutrients obtain additional supplies from other organs. Surplus nutrients or nutrients left over when growth is suppressed (such as drying the field) are temporarily stored for use when needed. The tillering period is the period in which nitrogen metabolism is prosperous. The color of the leaves is deep green. This is favorable to rapid expansion of the roots, leaves and tillers. All nutrients are transported to these new organs. During the end of tillering and the beginning of young panicle differentiation, the center of growth is in a process of change. By drying the field, the nitrogen metabolism is suppressed and carbon metabolism is increased, stimulating accumulation of carbohydrates. At this time, the color of the leaves becomes light. During the period from young panicle differentiation to panicle bearing, more nutrients are needed for the young panicles which are the centers of growth during this period. The color of the leaves must darken. The nutrients originally stored in the leaf sheaths and the stems must be rapidly transported to the young panicles to form the basis for the formation of large panicles. Three to 5 days prior to heading, the center of growth changes again and the color of the leaves lightens again but not too obviously. This pattern is the physiological basis for the alternating "two blackenings and two yellowings" referred to by the poor and lower-middle peasants, during the growth period of double season rice in the large fields.

The color of the leaves themselves also changes in phases. Within the same period, the color of the leaves at different positions is different. In general, a new leaf has a light color and the leaf below it has a dark color. The second leaf below it has already entered the functional stage and its color is even darker. The third leaf below it has reached the peak functioning period and its color is the darkest (the color of the third leaf is lighter than the second when there is a deficiency of fertilizers). The leaves below these four leaves are light green to withering yellow in color. When there is a sufficiency of fertilizers, the entire single leaf has a smooth and dark color. When there is a deficiency of fertilizers, the color at the tip of the single leaf begins to lighten and discoloring spreads to the base of the leaf to the leaf sheath.

In judging the changes in the color of the leaves, the color of the leaf sheath of the leaf is taken as the standard. If the color of the leaf blade is darker than the color of the leaf sheath, nitrogen metabolism is prosperous and accumulation of starch is minimal. When the colors of the leaf blade

and the leaf sheath are similar, more starch is being accumulated. When the color of the leaf blade is lighter than the color of the leaf sheath, carbon metabolism is prosperous and there is a lot of accumulation of starch. Vegetative growth visibly slows. The type of metabolism within the plant can also be determined by the reaction of the cross section of the leaf sheath to iodine. The starch in the leaf sheath accumulates from bottom to top. Iodine--a solution of potassium iodide--is applied on the cut of the leaf sheath of a longitudinally cut functional leaf. The solution will stain the leaf sheath partially. When the plant is undergoing expansive metabolism, the stained portion of the leaf sheath will remain at less than half the length of the entire length of the leaf sheath. When the plant changes into cumulative metabolism, the stained portion will extend to half or over half the entire length of the leaf sheath.

C. Size of the Leaves

The size of the leaves at various periods of growth reflects the level of nutrients at the moment and also reflects the quality of simultaneous extending organs. For example, the leaves emerging during the tillering period (leaf blade, leaf sheath) under normal conditions of growth increase in length one after the other and each leaf starts from the tillering node. In this way, the distance between auricles of neighboring leaf blades and leaf sheaths and the distance between the tips of neighboring leaves increase in a pattern. The distance between the auricles and the distance between the tips of leaves are large when the growth is rapid and prosperous. The respective distances are small when growth is slow and not prosperous. When growth is suppressed, the distance between the leaf blade and the leaf sheath of the upper leaves is short and may even be shorter than that of the lower leaves, forming a shrunken leaf like a "pot brush."

Because of simultaneous extension of leaves and tillers three positions apart, the photosynthetic products of the 6th and 7th leaves on the main stem after their emergence will definitely affact the growth and activity of the 8th and 9th leaves while the growth of the 8th and 9th leaves is simultaneous with the first leaf emerging from the tillers at the 5th and 6th leaf positions. Thus, the conditions of tillering can be determined by measuring the lengths of the 6th and the 7th leaves.

Surveys conducted by the Jiangsu Agricultural Science Institute showed that the last three leaves that grow parallel to the young panicles have progressively shorter lengths. For example, when the length of the reverse third leaf of the early rice plant "Ainanzao No 1" is 25.9 centimeters, the reverse second leaf is 26.5 centimeters and the flag leaf is 21.5 centimeters, growth of the plant is normal. Conversely, if the length of the reverse third leaf is 25.1 centimeters, the reverse second leaf is 28.3 centimeters and the flag leaf is 26.8 centimeters, then growth is overly prosperous. Another example is the variety "Ainanzao No 39." When the reverse third leaf is 21.0 centimeters long, the reverse second leaf is 21.6 centimeters long and the boot leaf is 21.6 centimeters long, normal growth is indicated.

Thus, controlling the lengths of the three uppermost leaves will effectively solve the conflict between the area of photosynthesis and the photosynthetic ability during the middle and latter periods of growth of the colony. But before emergence of these three leaves, observation and judgement can be made by observing the emergence of the reverse fifth leaf. The color of the leaf should turn to dark green and the length of the leaf should be between 18 and 22 centimeters.

D. Surface Area of Leaves in a Colony

The area of the leaves in a colony determines the percentage of utilization of light energy. If the area of the leaves is not large enough, not enough photosynthetic products will be produced. But if the area of the leaves is too large, aeration and light permeability will be affected, individual growth will be weakened, the ability of photosynthesis will be reduced and yields will not be high, even leading to lodging and reduced yields. The pattern of change of the area of leaves in the colony is: During the early period (from transplanting to the time before jointing), the area of leaves in the colony increases as the number of tillers increases. During the middle period of growth (from jointing to the time all flag leaves have emerged), the area of leaves in the colony increases as the surface area of the leaves increases. During the latter period of growth (from the time all the flag leaves have emerged to maturation), the area of leaves in the colony is determined by the life of the leaves. The most ideal leaf surface area is characterized by good light permeability during the early period with a high rate of utilization of light energy. Growth is rapid and more dry substances are accumulated. During the middle period, growth should not be too fast to avoid reducing the rate of utilization of light energy and thereby affecting the formation of strong stems and large panicles. During the latter period of growth the functioning period of the leaves should be extended to create favorable conditions for increasing the weight of the grains and reducing formation of semi-filled grains.

The area of the leaves in the colony is usually represented by the leaf area coefficient (or called leaf area index). The leaf area coefficient refers to the multiple of the area of the leaves over a unit area of land. Methods to determine the leaf coefficient are usually the dry measurement method or the length x width conversion method. The dry measurement method involves weighing the dry weight of an entire sample of green leaves and the dry weight of green leaves of a definite surface area taken from the sample. Then, the area of green leaves of the entire sample can be calculated from the unit weight of the area of the leaves of the sample (centimeter^2/gram) and from the dry weight of the green leaves of the entire sample and converted into the area of green leaves of the single plant (or single stem). The total area of the leaves in one mu of land is calculated from the total number of basic seedlings per mu (or number of stems) and then divided by the area of 1 mu. The number obtained is the leaf area coefficient. The length x width conversion method involves directly measuring the length and the width at the widest part of each leaf of the sample plants, multiplying the two measurements and their product by 0.75. The product is the area of green leaves. The sum of the area of the leaves of all the samples is the area of green

leaves of the samples. This figure is taken to calculate the area of leaves per mu and the leaf area coefficient.

E. Reduction or Increase of Tillers

The number of panicles is determined by the main stem and the number of effective tillers. Thus when the basic number of seedlings is satisfied, early tillering and plentiful tillering must be stimulated to assure a sufficient number of panicles. Surveys of large areas indicate the numbers of panicles, grains and weight of grains can be uniformly managed when there are 400,000 to 450,000 panicles per mu in the double season rice fields. Thus, a reasonable reduction or increase in tillerings can also be determined by the expected number of panicles. In large area production, tillering should begin within 7 to 10 days after transplanting and the plants should be allowed to grow until 15 days prior to jointing (about half a month after transplanting [jointing is 20 days after transplanting] so that the total number of tillers per mu will equal the expected number of panicles, between 400,000 and 450,000 for double season rice. Afterwards, tillering must be slowed so that the trend of growth can remain stable. At the time before jointing (about 20 days after transplanting), tillering reaches its peak and the highest number of tillers on the stems per mu for early rice reaches between 600,000 and 700,000 and the number for late season rice reaches between 500,000 and 600,000, about 30 percent more than the expected number of panicles per mu. The occurrence of 30 percent of ineffective tillers is an indicator of healthy growth of the main stem and effective tillers. After jointing, the number of tillers drops gradually until the final percentage of panicle formation reaches about 70 percent. This percentage is most suitable for realizing full panicles, large panicles and high yields.

Besides considering the pattern of reduction or increase of tillers, the date of closing the rows must also be grasped. After the rows of the fields have closed, the light upon the middle and lower leaves visibly weakens. Under this weak light photosynthesis weakens and the root system's development is affected. At the same time, under weak light, the internodes at the base of the plants easily elongate. This is not favorable to synthesis of such polysaccharides as cellulose. The tissues are tender and weak and especially given conditions when the amount of nitrogen fertilizers is sufficient, closing of the rows becomes even more serious. Thus, paddy rice fields must not close their rows within 15 days after jointing. The most suitable time to close the rows of a paddy rice field is between 15 and 20 days after jointing. At this time, the first internode of intermediate rice and late rice has already filled, the second internode has already established its length and the plant is basically resistant to lodging. Although the first internode at the base of the early rice plant has not yet completed filling, the burden of its stems is lighter than that of intermediate and late rice because the plant is generally shorter, its center of gravity is low and its panicles are light in weight. Thus, closing the rows at this time will not increase the possibility of lodging. Of course, the time for closing the rows must not occur too late. Closing the rows too late indicates insufficient growth of the colony and high yields cannot be achieved.

Determination of the date of closing the rows: The time of closing the rows is the time when the tips of the flag leaves begin to emerge, or when the intensity of light in the hole at one third of the height of the plant is 5 percent of the intensity of natural light, or when a man standing on the bank of the field cannot see the surface of the field or the surface of the water one meter beyond the row of paddy rice plants.

II. Applicability of Indicators in Each Stage of Growth

Double season rice fields that produce 1000 jin per mu with above average soil fertility require 40,000 to 50,000 holes per mu or 250,000 to 300,000 basic number of seedlings. The production structure at maturity consists of 400,000 panicles per mu with 40 to 50 full grains on each panicle and a 1000 grain weight of between 25 and 27 grams. To realize the above yield, observation and diagnosis of the seedlings should be made at each growth period and a definite trend and appearance of growth must be grasped for each stage of growth.

A. Trends and Appearance of Growth During the Tillering Period

Roots emerge 3 days after transplanting. Within 2 to 3 days, from several to over 10 new roots emerge. The number of roots increases faster as time passes. The plant begins to green 5 days after transplanting. The color of the leaves turns from a light color to bright green. Seven days after transplanting, tillers emerge (or emerge abundantly at the time when the tip of the second new leaf emerges after transplanting). Seedlings achieve full growth 15 days after transplanting and the total number of tillers on stems of the entire field reaches 400,000 to 450,000. By this time, several scores of new roots emerge. The color of the leaves turn dark, reaching the darkest color during the entire life of the paddy rice plant. The color of the leaf blades must be darker than that of the leaf sheaths. The leaves must be curly but not drooping. The auricle distance must progressively increase. Twenty days after transplanting, tillering reaches its peak. The entire field should have between 500,000 and 600,000 tillers. Early rice plants may have more tillers, sometimes reaching 700,000 (Table 142).

Stunted seedlings that do not grow can be determined when the color of the leaves is deep green but the new leaves appear yellow, leaves do not overlap, there are very few new roots, old roots are thin and long, black roots emerge and the distances between auricles do not increase progressively. The causes of these phenomena must be sought among factors that affect early growth such as temperature, depth of transplanting, soil condition and fertility and damage by insect pests. Timely remedies must be implemented. At the end of tillering or the beginning of young panicles differentiation, the color of the leaves gradually lightens until the color of the leaf blades is lighter than that of the leaf sheaths; the leaf blades are erect while the leaf sheaths are short and thick. If the color of the leaves at this time is too deep and the leaf sheaths are too thin and long, if the distances between auricles increase drastically, if the leaves of the seedlings droop

in the morning, if the seedlings bend and hang downward at noon and if the apex of the leaves emits water late and in minute amounts at dawn (the vitality of the root system has weakened), if the total number of tillers in the field is overly high, then the paddy rice seedlings have grown too much. Application of nitrogen fertilizers should be controlled and the field should be dried in a timely manner.

Table 142. Appropriate Range of Indicators for Diagnosis During the Tillering Period

Range of indicators / Item	Number of days after transplanting				Remarks
	7 days beginning of tillering period	10 to 15 days Prosperous tillering period	20 days peak tillering period	30 days ending period of tillering	
Color of leaves	Darker than color of leaf sheath			Lighter than color of leaf sheath	Combination of information from various localities
Auricle distance	Each leaf steadily increases				
Color of root	white	white, yellow	yellow	yellow, white	
Leaf surface area coefficient	2.0	5.0	6.0		
Total number of tillers on stems per mu	—	40 45	50 60		

B. Trends and Appearance of Growth During Jointing and Panicle Bearing Periods

At this time the color of the leaves has already begun to drrken. The color is similar to the color of the leaf sheath or darker. The reaction of the leaf sheath to iodine reaches half or more than half the length of the leaf sheath. The entire field seen from afar appears light green (the main color of the tips of the leaves) while seen from nearby appears bright green. When the tips of flag leaves emerge (about 15 days prior to heading), the color of the leaves must visibly return until 3 to 5 days before heading when the color recedes. If the color of the leaves is too dark or the plant does not return to its former position after being pushed sideways because it has lost resilience, then too much nitrogen fertilizer has been

applied and the colony is too large. There is the possibility during the latter period of growth that the plants may lodge and the fruiting percentage may drop. Conversely, if the leaves show a definite "yellow" during the beginning period of young panicle differentiation, if the tips of the leaves that have just entered the functional stage also appear "yellow" and if the leaves at the base of the plant wither and die early, then there is a deficiency of fertilizers. Fertilizers for growth of panicles must be applied at this time.

Table 143. Appropriate Ranges of Each Indicator of Diagnosis During Jointing and Panicle Bearing Periods

Range of indicators / Items	Growth periods			Remarks
	Young panicle differentiation period	Panicle bearing period	3 to 5 days before heading	
Color of leaf	Similar to that of leaf sheath	Darker than that of leaf sheath	Lighter than that of leaf sheath	Combination of information from various localities
Leaf surface area coefficient	6.6	8.0	--	
Lengths of last three leaves (cm)	reverse 3rd 25.9	reverse 2nd 26.5	flag leaf 21.5	

After the panicle bearing period, the color of the roots is not as clearly visible as during the tillering period. At this time, observations mainly depend upon the depth of the roots. In general, strong and healthy paddy rice seedlings have deep roots and the plant is not easily uprooted. The portion of the tips of the roots that is white is long. Paddy rice seedlings that have shallow roots and roots that wither early can be uprooted easily and the portion of water by the tips of the leaves can also serve as an indicator of the vitality of the root system. When there are no strong winds and the temperature is not too high, leaves of paddy rice seedlings that have an active root system will emit water early at dusk and the droplets of water are large. Conversely, if the leaves emit water late and the droplets are small, the root system is weak. When the root system withers and dies, the leaves are not able to emit water droplets from the tips.

C. Trends and Appearance of Growth During the Heading and Fruiting Periods

Uniform heading and uniform panicle heads are manifestations of the growth trends during these periods. The period between the beginning of heading and full heading should be between 5 and 7 days. The color of leaves should be darker than that before heading. Early rice should have 4 green leaves on the main stem or the single tiller. Intermediate and late rice should have 5. During the milky ripe stage, early rice should have 3 green leaves. Intermediate and late rice should have 4 green leaves. During the yellow ripe stage early rice should have 1.5 green leaves and intermediate and late rice should have 3 green leaves. If the color of the leaves is dark green, the reverse fourth leaf has already withered and yellowed before heading and the branches appear dark green, then the plant

is remaining green and will mature late. This is usually caused by an inadequate application of fertilizers and untimely drying of the field. Management of irrigation and muddiness of the field should be intensified to extend the life of the root system. It is difficult to use other methods to remedy the situation. Conversely, if the leaves rapidly yellow after heading and the tips of the functional leaves visibly turn yellow, then the plant is withering early and proper application of pellet fertilizers will definitely increase the yield.

III. Diagnosis of Physiological Hindrances

In the entire process of growth of paddy rice, certain adverse external conditions or improper measures of cultivation will cause certain physiological hindrances to the growth of the paddy rice plant. For example, stunted growth of seedlings during the early period of early rice, early heading during the middle period of growth, formation of empty and semi-filled grains during the latter period of growth, lodging, early withering and formation of "raised panicle heads" of late season rice often affect the normal growth of paddy rice and seriously damage the yield. Thus, these physiological hindrances must be correctly diagnosed and their causes analyzed so that necessary preventive or remedial measures can be taken to assure high yields.

A. Seedling Stunting of Early Rice

Stunting of early rice seedling is a physiological hindrance during the tillering period of early rice. It mostly occurs in early rice following green manure crops. In the middle and lower reaches of the Chang Jiang regions, the causes of seedling stunting are both internal and external. The internal causes are poor quality of the seedlings, having a small leaf age, having a low level of sugar and nitrogen in the plant body and having deficient amounts of phosphorus and potassium in the plant body. The external causes are low temperatures and strong reducing characteristics of the soil. Stunted seedlings can result from three types of causes: damage by cold, poisoning and deficiency of elements. If the plants are transplanted too deeply, mismanaged and infected by insects and diseases, stunting of the seedlings will occur even more severely.

1. Damage by cold

The symptoms are manifested by a light green with yellow color of the leaves spotted by brownish irregular acicular spots concentrating at the tips of the leaves. Seriously affected leaves wither along the rims from the tips to the base of the leaves. The paddy rice plants appear bunchy, soft and do not tiller. The roots of the paddy rice plants are brown and soft as cotton with poor resilience. New roots are thin and few. When the temperature is low (average daily temperature below 15°C) and the difference in temperatures during day and night is great, the formation of chlorophyll is destroyed by low temperatures during the night. "Fragments of yellow" or "fragments of white" emerge on the leaves. This is due to suppression of the activity of the root system by low temperatures and weakening of the ability of the root system to absorb nutritional elements. Such damage is

often accompanied by a physiological deficiency of phosphorus and nitrogen. The method to remedy seedlings that have been stunted due to damage by cold is to use water to regulate the temperature, dry the field during the day to increase the temperature, irrigate the field at night to retain temperature and apply immediately effective nitrogen fertilizers. These measures will bring about definite results.

2. Poisoning

Many substances will poison the paddy rice seedling. Stunted seedlings poisoned by bivalent iron will have roots that are rarely coated by rust or only a few roots will have a partial coating of rust spots. There are often branch roots at the tip of the roots and the soil surrounding the roots appears greenish gray. Brown colored spots emerge at the tip of the lower leaf and gradually spread to the base of the leaf until the entire leaf is brown. The degree of poisoning can be tested by use of the testing agent $C_{12}H_8N_2$ applied to the cut at the base of the leaf on the stem. The agent combines with bivalent iron in the body of the rice plant to form a red compound $(Fe(C_{12}H_8N_2)_2)^{++}$, and the more bivalent iron there is in the body of the plant the deeper the color of red. When the content of bivalent iron in the soil accumulates to above 50 ppm, it becomes poisonous to the paddy rice plant. Bivalent iron mainly suppresses absorption of nutritive elements by the roots in this order: Phosphorus, manganese > potassium > > silicon > nitrogen > calcium. Thus this type of stunting of seedlings is often accompanied by a physiological deficiency of phosphorus.

Stunted seedlings damaged by organic acids have roots that have shrunk and few new roots. When poisoning is serious, the epidermis of the root peels off and some roots appear transparent and even rot. The leaves yellow and when seriously affected the lower leaves yellow, wither and die. The plant remains small.

The most abundant organic acid in the paddy rice field is acetic acid (nearly 50 percent), followed by butyric acid, formic acid and lactic acid. Acetic acid can be tested by drops of lanthanum nitride ($La(NO_3)_3$). The sensitivity of paddy rice to organic acid poisoning during different stages of growth is different. Studies indicate during the greening and tillering periods the paddy rice's root system has the weakest resistance to organic acids. When the free organic acid ions in the soil reach a concentration of 0.001 mole, poisoning of the plant occurs.

Poisoning by hydrogen sulphide is characterized by a repugnant smell when the plant is uprooted. The entire root system is black or dark gray and there are very few white roots. The remaining white roots are thin and weak. When exposed to air, the black ferrous sulphide is oxidized to yellowish brown ferric hydroxide. Black roots become brown roots. The leaves are yellowish brown and the tips of the leaves are withered. The lower leaves wither and die, leaving only 1 or 2 new green leaves. Existence of sulphides inside the body of the rice plant can be detected by cutting the base of a leaf of the stem longitudinally and tested by a drop of 1 percent $(CH_3)_2NC_6H_4NH_2 \cdot 2HCL$ and 1 percent of ferric chloride solution. If the plant contains any sulphides, the solution will appear blue (methylene blue). The

deeper the blue color the more sulphides there are. When the content of hydrogen sulphide in the paddy rice field reaches 0.7 to 2.0 ppm in concentration, poisoning will occur.

The poisoning effect of hydrogen sulphide is mainly due to its suppression of the respiratory function of the root system and the absorption of nutrients by the root system in the following order: Potassium > phosphorus > > silicon > manganese > nitrogen > magnesium and calcium. Because the absorption of potassium and phosphorus is suppressed the most, paddy rice seedlings affected by poisoning often show a deficiency of potassium and phosphorus.

The cause of poisoning is due to the overly strong reducing characteristics of the soil and weakening of oxidation by the roots. Some fields with a lot of fresh green manure plowed under or a lot of organic fertilizers that have not rotted will easily become poisonous to plants because of their content of organic acids and hydrogen sulphide. Poisoning of plants by bivalent iron easily occurs in fields that are seriously deficient in oxygen because of the lengthy periods of irrigation and contain a lot of iron.

The remedial method is to increase aeration of the paddy rice field in order to allow air to enter the soil and oxidize the poisonous substances. Thus, the field should be drained and lightly held in a timely manner. Imediately effective nitrogen and potassium fertilizers should be increased (potassium can heighten vitality of the root system and visibly increase the resistance of the paddy rice seedling to poisonous substances) to stimulate the vitality of the paddy rice seedling.

3. Deficiency of nutritive elements

(1) Deficiency of phosphorus: Symptoms of a deficiency of phosphorus are manifested when the new leaves appear dark green, old leaves appear grayish purple, the blades of leaves are erect and the proportion of the leaf and the leaf sheath is abnormal (the leaf sheath is long and the leaf blade is short). When the plant is seriously affected, the leaves curl up slightly along the veins or appear folded. The roots are thin, soft and lack resilience and branch roots are few. The root system is not extensive. The plant does not manifest any other particular symptoms.

Deficiency of phosphorus can be determined by molybdenum blue. Three to five representative plants are taken, washed and their roots cut, their wilted leaves removed, their leaf sheath tissues cut from the botton into pieces 2 millimeters in length. Then 1 milliliter of shredded leaf sheaths is placed in a 15 milliliter test tube and 2 milliliters of hydrochloric molybdic acid ammonium solution are added (the solution should cover the shredded leaves). The test tube is covered tightly and shaken 300 times (about 2 minutes). The test tube is then opened and 8 milliliters of water are added and the contents stirred. A drop of stannous chloride glycerine is added to the contents and the contents are shaken again. After 5 minutes, the color is observed. A slight deficiency of phosphorus is indicated by a light blue color. Sufficient phosphorus is indicated by a deep blue color.

Stunting of seedlings due to lack of phosphorus usually occurs when the inorganic phosphorus content in the leaf sheath is below 30 ppm. Deficiency of phosphorus may occur in two situations: One is deficiency of phosphorus in the soil. Surveys show when the total amount of phosphorus in the soil is below 0.1 percent and effective phosphorus in the soil is below 5 ppm, the paddy rice plant will manifest symptoms of deficiency of phosphorus. The other kind of deficiency is physiological deficiency of phosphorus caused by low temperatures and an over abundance of reducing and poisonous substances which hinder the absorption of phosphorus by the root system.

Remedial measures include the application of phosphorus fertilizers to soil deficient in phosphorus. To remedy the physiological deficiency of phosphorus, the hindrances to absorption of phosphorus must first be removed. In addition, when the content of nitrogen in the body of the paddy rice plant is sufficient, inorganic phosphorus can be stimulated and converted into such organic phosphorus as nucleic acid and nucleoprotein. In this way, the paddy rice seedling's absorption and utilization of inorganic phosphorus can be stimulated. Thus, stunted seedlings deficient in phosphorus must be supplied with phosphorus fertilizers as well as nitrogen fertilizers.

(2) Deficiency of potassium: Symptoms of deficiency of potassium are generally manifested during the middle and latter periods of tillering of the paddy rice plant. Reddish brown spots first emerge on the tips of the old leaves and spread from the tips to the base of the leaves and from the old leaves to the new leaves forming reddish brown stripes or striped spots. On some plants, such symptoms also appear on the leaf sheaths so that the entire leaf or the entire plant becomes reddish brown in color with only a few new leaves still remaining green. Observations indicate before xian rice plants are affected by spots on the tips of the leaves, the color of the tips of the leaves first recedes and yellows as a preliminary symptom. Geng rice plants, on the other hand, do not manifest such preliminary symptoms. Extension of the roots of the paddy rice plant is hindered and root hairs appear only at the tips of the branch roots. They develop poorly and shed easily. The entire root system appears yellowish brown or even black. Deficiency of potassium often accompanies cold damage and poisoning which stunt the seedlings. The phenomena are usually referred to as the physiological red withering disease.

The content of potassium in the rice seedling can be tested with nitrous cobalt sodium $Na_3(Co(NO_2)_6)\cdot\frac{1}{2}H_2O$. An upper leaf or leaf sheath of the seedling is taken and cut into shreds. A small portion of the shreds is placed in a test tube and 3 milliliters of nitrous cobalt sodium agent are added. The contents are shaken violently for 1 minute. Then 1 milliliter of 95 percent alcohol is immediately added to the contents which are then stirred and allowed to stand for 5 minutes. The degree of clarity of the solution is observed. When potassium is seriously deficient, the solution will be clear. When potassium is slightly deficient, the solution will be slightly unclear. When there is no deficiency of potassium, the solution remains murky.

The reasons for deficiency of potassium are complex. In the Shanghai area, for example, there is generally no deficiency of potassium fertilizers, but as the use of nitrogenous chemical fertilizers increases and as the amount of organic fertilizers being used correspondingly lessens, the ratio of potassium to nitrogen is out of balance (the ratio of potassium to nitrogen is less than 0.5). This easily causes stunted seedlings due to a deficiency of potassium. Sometimes damage by cold and poisoning that cause stunted seedlings are also accompanied by a physiological deficiency of potassium. When such situations are encountered, the hindrance to absorption of potassium must first be removed and then potassium fertilizers should be applied. Thus, in the Shanghai area, when stunting of seedlings occurs because of a deficiency of potassium, phosphorus and potassium fertilizers must be applied in increased amounts and the simple and sole application of nitrogen fertilizers used in the past must be changed.

In addition, transplanting the seedlings too deeply, irrigating too deeply, deficiency of nitrogen, plant diseases and insect pests will also cause stunted seedlings. When the seedlings are transplanted too deeply, the underground portion of the plant forms "two section roots or three section roots" delaying tillering. Long durations of deep water irrigation will cause the base of the seedlings to whiten and the portion of the plants above ground will manifest "peeling of the leaves and extension of the new leaves." Stunting of seedlings caused by a deficiency of nitrogen is indicated by a lightening of the color of the leaves, and yellowing and early withering of the lower leaves. New leaves do not curl up tightly but open up fast while the plant type remains erect. Stunting of the seedlings may also be caused by such insects as rice thrips and agromyzidae. Remedial measures should be taken according to actual situations.

B. Early Formation of Panicles

Early formation of panicles is also called "small panicle heads." This refers mainly to the phenomena of the panicle beginning to differentiate or develop while the seedling is in the seedbed and the plant heading soon after transplanting. In general, this easily occurs in overaged seedlings of early rice's early maturing varieties or early rice [sic] varieties of late season rice.

1. Symptoms

Early formation of panicles may occur as early as over 10 days after transplanting and heading occurs no later than a month after transplanting. Since tillering is not uniform, heading occurs early but full heading occurs late and the heading time is extended. The plants with such early panicles are smaller than plants that head normally. The color of their leaves is light and tillers are few. The panicles are small and semi-filled grains are abundant. Some panicles do not have flag leaf sheaths and the yield is thus reduced.

2. Causes

The inner cause of the early formation of panicles is the strong sensitivity to temperatures of early rice varieties. Their entire growth period is short and when the seedlings are over-aged, the effective cumulative temperature needed by the variety will have already been reached. Hence, the young panicles begin to differentiate. External causes are overly high temperatures during the seedling cultivation period or over-aging of the seedlings coupled with too large amounts of seeds sown and too much control of fertilization and irrigation. The individual plant's nutritive area is small and the nutritive conditions are poor, easily causing the plant to shrink abnormally during the vegetative growth period. The plant quickly changes into reproductive growth so that young panicles begin to differentiate while the plant is still in the seedbed stage or soon after transplanting, leading to formation of early panicles. Because the young panicles differentiate under poor nutritive conditions, the panicles are small and semi-filled grains are plentiful. Observations by the Shanghai Municipal Academy of Agricultural Sciences show varieties with short growth periods require fewer days between sowing time and young panicle differentiation and thus cannot tolerate lengthy seedling ages (Table 144).

Table 144. Young Panicle Differentiation Period of Early Rice Varieties (Shanghai Municipal Academy of Agricultural Science, 1975)

(a)	(h)	(c)	(d)	(e)	(f)	(g)
(h)	1973	4/19	5/17	5/27	38	10
	1974	4/21	5/18	5/27	36	9
(i)	1973	4/22	5/22	6/2	41	11
	1974	4/22	5/22	5/31	39	9
(j)	1973	4/25	5/30	6/14	50	15
	1974	4/26	6/1	6/13	48	12
(k)	1973	4/18	5/31	6/14	57	14
	1974	4/21	6/3	6/13	53	10

Key: (a) variety
(b) year
(c) sowing time (month/day)
(d) transplanting time (month/day)
(e) date young panicles begin differentiation (month/day)
(f) number of days from sowing to beginning of young panicle differentiation
(g) Number of days from transplanting to beginning of young panicle differentiation
(h) Erjiulu No 1
(i) Ainanzao No 1
(j) Ainanzao 39
(k) Guangluai No 4

3. Remedial methods and measures

To prevent occurrence of small panicle heads, the characteristics of the varieties must be considered to determine the most appropriate sowing time

and seedling age. The plants must be sparsely sown in a suitable manner and the amount of sowing should be determined by the length of the seedling age to assure that each seedling will have a definite nutritive area and that development of the individual plant is not suppressed. The management of fertilization and irrigation of the seedbeds must be intensified and control of the growth of the seedlings of varieties with short growth periods should not be done by controlling fertilization and irrigation. Seedlings that are over-aged should be given a sidedressing of fertilizers as a remedial measure before transplanting to facilitate greening and early tillering after the seedlings are transplanted. This stimulates vegetative growth and delays the time of young panicle differentiation. The seedlings must be transplanted shallowly for early tillering. The large field must be managed well after transplanting, fertilizers should be applied heavily and the field should be weeded deeply to stimulate vegetative growth.

C. "Raised Panicle Heads" of Late Rice

1. Symptoms

"Raised panicle heads" of late season rice are panicles with a high percentage of empty and semi-filled grains. The panicles do not hang down because of its empty and semi-filled grains formed as a result of abnormal fertilization and fruiting after heading.

2. Causes

"Raised panicle heads" will emerge as a result when large amounts of empty grains are formed because normal development of pollen grains and germination are suppressed during the period from panicle bearing to heading and flowering of late season rice. Also, a persistance of an average daytime temperature of below 20°C for 3 days, a persistance of an average daytime temperature of below 22°C for 5 days, or a persistance of a lowest temperature below 17°C (some say 15°C) for 3 days will also cause "raised panicle heads" to form.

3. Method to prevent "raised panicle heads"

(1) The sowing time should be determined according to the characteristics of the variety and the safe full heading period of the locality so that sowing is timely and transplanting of the seedlings is done at the proper age to assure full heading. In the Shanghai area, the sowing time of late geng varieties must not be later than June 15, the sowing time of early maturing late geng varieties must not be later than early July, the sowing times of intermediate geng and intermediate nuo must not be later than July 5, and the sowing time of early rice varieties [sic] must not be later than July 25. Otherwise, "raised panicle heads" will occur. Transplanting of late season rice must be early. The conflict between early transplanting of late season rice and "nourishing the aged" early rice should be correctly handled. Thus, late season rice should be transplanted by August 12.

(2) Cultivation of strong seedlings: The length of the seedling age and health of the seedling determine to a definite degree whether late season rice can achieve safe full heading and the expected amount of yield. Varieties of late season rice presently being cultivated in production have a growth period of between 130 and 150 days. The period of growth in the seed bed constitutes about one-third of the entire growth period and in particular, five-sixth of the vegetative growth period are spent in the seedbed period. Vegetative growth is the foundation for reproductive growth. Healthy and strong seedlings have larger assimilative organs and better root systems and can accumulate more nutrients. After they are transplanted to the large fields, they green early and develop rapidly and are strongly resistant to low temperatures and cold.

(3) Taking preventive measures: When low temperatures are forecasted during the heading and flowering priods, preventive measures to resist low temperatures must be exercised such as draining the field during the day to increase the temperature, irrigating the field with a deep layer of water to retain the temperatures at night, spraying a low concentration of "920" hormone to stimulate early heading and spraying calcium superphosphate solution around the roots (3 jin of calcium superphosphate diluted by 100 jin of water for each mu) and urea (1 jin diluted by 100 jin of water per mu) to increase resistance to low temperatures.

D. Empty and Semi-Filled Grains

1. Symptoms

Empty grains have completely developed palea and lemma but because of various reasons fertilization is hindered and the ovaries cease to develop. Semi-filled grains are grains whose spikelets have been fertilized but filling is obstructed in the middle of the filling process and the grains cease to develop further (When the glumes are peeled open, unformed rice grains can be found). Semi-filled grains generally cease to develop within 15 days after heading. Thus the 1000 grain weight is light, generally constituting only 1/3 of the weight of the filled grain. Semi-filled grains will not germinate.

2. Causes

Physiological causes of empty grains can be contributed to defective female and male sex organs which cannot complete the fertilization process, for example, incomplete development of the pollen mother cell, incomplete emergence of multinuclear microspores from division of the quadruplet, failure of the pollen to germinate, weak ability to open the glumes, hindrance to the formation of the cell in mitosis, failure of the chromosomes to couple and an overly thick tissue layer of pubescence on the inside wall of the anther. A physiological cause of semi-filled grains is the inability of the supply of nutrients to reach the panicles after fertilization. This causes the development of the ovary to cease or the growth of the endosperm to terminate during the filling process.

External causes of empty and semi-filled grains include adverse weather and inadequate methods of cultivation. Adverse weather conditions are mainly caused by temperatures. The pollen mother cell cannot develop normally when an average daytime temperature of below 17°C persists for over 3 days. During the heading and flowering period, the glumes will not open and fertilization cannot be realized normally when the average daytime temperature is below 20°C or when damp and rainy days continue for 3 days and light and temperature conditions are insufficient. During the period of filling, the most suitable temperature should be between 21°C and 25°C. Temperatures that are too high or too low will hasten or slow the process of filling and both of these affects are unfavorable to complete filling of the grains.

Adverse conditions of cultivation mainly refer to inadequate management of fertilization and irrigation. If too much nitrogen fertilizer is applied or insufficiently applied and if the paddy rice field is submerged under water for a lengthy period, the number of semi-filled grains will increase.

3. Measures of prevention

(1) Selection and use of superior varieties: Because the characteristics of form and physiology of paddy rice varieties are different, the percentage of fruiting of the varieties is also different. Thus, varieties with strong resistance to adversity and high fruiting percentages should be selected and used.

(2) Timely sowing: Early rice following green manure crops should not be sown too early to avoid low temperatures during the panicle bearing period which affect normal development of the pollen mother cells. Late season rice should not be sown too late to avoid low temperatures during the latter growth period which affect fruiting.

(3) Reasonable management of fertilization and irrigation: This prevents early withering during the latter growth period, prevents the plant from remaining green and maturing late, strengthens the vitality of the root system and assures normal manufacturing, transportation and accumulation of nutrients in the panicles during the latter period of growth.

(4) Timely prevention of insect pests and plant diseases.

E. Lodging

1. Symptoms

There are two types of lodging of the paddy rice plant: One is the type of lodging in which the plant lies on the ground. This is mainly caused by an overly mushy field, poor development of the root system and roots that are shallow and lack supportive strength. After jointing the stems extend upward and the center of gravity shifts. The plant falls to the ground when

wind blows and rain falls. Surveys conducted by the former Jiangsu Branch of the Chinese Agricultural Science Academy show that paddy rice plants that do not lodge generally grow to 24 centimeters in the plowing layer, the dry weight of the roots in each planting hole averages 5.83 grams and 27.1 percent of the roots are distributed in the soil layer between 12 centimeters and 24 centimeters deep. The dry weight of roots per hole of paddy rice plants that lodge averages only 4.78 grams and only 15.9 percent of the root system is distributed in the plowing layer between 12 centimeters and 24 centimeters deep. This shows that paddy rice plants that lodge have poorly developed root systems and the root system is distributed shallowly. The other type of lodging consists of different degrees of slanting caused mainly by poor development of the base of the stem, overly long internodes at the base, soft tissues of the stem, weak resistance to breakage and inability of the stem to carry the weight of the upper part of the plant, thus different degrees of lodging occur (Table 145).

Table 145. Relationship Between Length of Internodes and Lodging (Shanghai Municipal Academy of Agricultural Science, 1975)

Condition of lodging	Part of the plant above ground (cm)			Remarks
	1st node	2nd node	3rd node	
Lodging	1.56	7.2	14.1	Variety:
Does not lodge	0.88	3.2	8.2	Jianong 485
Difference	0.68	4.0	5.9	

2. Causes

(1) The plowing layer is too shallow: Whether the root system of paddy rice grows well is closely related to the depth of the plowing layer. Plowing the soil too shallowly or an overly thin plowing layer will affect the development of the root system. The roots will not be able to root deeply. Hence, the support for the upper part of the plant is weak. Paddy rice fields with a shallow plowing layer cannot accommodate too much chemical fertilizers. The plants will grow too prosperously and will lodge.

(2) Lengthy irrigation without draining: Because the paddy rice stem extends according to the depth of the water layer in the field, lengthy irrigation without draining the field will cause the aerate tissues in the stem to enlarge and the walls of the cells to become thin. The spaces among the cells will enlarge and the tissues will be loosely structured. At the same time the roots will not develop well nor root deeply. When the weight of the upper part of the plant increases during the flowering and filling periods, wind and rain will cause the plant to lodge.

(3) Plant diseases and insect pests: When rice leafhoppers, rice leaf rollers, sheath and culm blight of rice and blast of rice seriously affect the paddy rice plant, the tissues of the stem are destroyed and the plant will also lodge.

3. Measures to prevent lodging

(1) Deep plowing: Deep plowing is to plow the soil to a depth of 5 cun so that the plowing layer will be thick and the soil's ability to retain water and fertilizers can be increased.

(2) Timely drying and managing irrigation and muddiness of the field by alternating dryness and dampness will stimulate the growth of new roots to root deeply and suppress over elongation of the internodes at the base of the plant, thus increasing resistance to lodging.

(3) Plants that have lodged should be erected and let them lean against those plants that have not lodged in rows like rows of scales on the fish. This procedure prevents the grains from germinating and rotting.

F. Early Withering

1. Symptoms

During the latter growth period of paddy rice (from heading to maturation), adverse external conditions will cause the leaves to "wither while still young." The color of the leaves become brown. The tips of the leaves appear grayish white, a sign of dying. The leaves are thin and curled and seen from afar the field appears like a blanket of withered leaves. The growth of the root system is weak and the roots themselves are soft and weak. Some black roots may even occur.

2. Causes

Early withering may be caused by plant diseases and insects but it may also be a form of early physiological withering. The reasons for such withering are more complex. If during the latter growth period the conversion of nutrients accumulated in the body of the plant is rapid, then under conditions in which the root system is weak and management of irrigation and fertilization is poor, the leaves will wither early. If irrigation is cut off too early during the latter period of gorwth and fertility lags in strength, the content of nitrogen in the leaves will lessen, growth will become weak and the leaves will age and wither early. Overly dense growth will cause the plants to close towards each other, causing a suffocating condition. The ability of photosynthesis of the reverse fourth leaf weakens and the vitality of the root system is affected. The roots of the paddy rice plant wither early and lose their ability to preserve the leaves. The photosynthetic function of the three uppermost leaves also weakens. The leaves wither and yellow early. Adverse weather conditions such as hot winds and cold fronts may also cause early withering. If the temperatures during the latter period of growth of early rice are high, varieties with weak resistance to adversity will suffer from weak growth because of a lack of fertility or because irrigation has been cut off too early. The leaves will wither and age early. If temperatures during the latter period of growth of late season rice are low, varieties with a weak resistance to adversity will wither early in low temperatures. Late season rice will also wither early during cold fronts because the physiological activity of the roots and the leaves is hindered.

3. Methods of prevention

The key to prevention is to manage fertilization and irrigation well in order to avoid cutting off irrigation of early rice too early. In cultivating late season rice, the field should be irrigated deeply to retain the temperature in the field when low temperatures occur. In regions where the soil is heavy in texture and aeration is poor, the method of alternating dryness and dampness of the field during the latter period of growth should be used to solve the conflict between water and air in the soil and to retain the activity and vitality of the root system. Paddy rice plants that wither early because of a lack of fertilization should be provided with additional pellet fertilizers in appropirate amounts after heading (fast results can be obtained by applying sidedressing around the roots).

G. Remaining Green

Before and after the paddy rice plant heads, the dark green color of the leaves, overly large flag leaves and drooping leaves during the morning when the leaves are covered with dew indicate that the plant is remaining green.

Paddy rice plants remain green mainly because of the inadequate management of irrigation and fertilization during the early and middle periods of growth, when sidedressings are applied and especially when immediately effective nitrogenous fertilizers have been applied singularly.

The key to preventing the plant from remaining green is to strengthen management of irrigation and fertilization during the early and middle periods of growth. If the phenomenon of remaining green occurs during the latter period of growth, the field should be dried slightly several times before and after heading.

H. Damage by Herbicides and Insecticides

Paddy rice can be damaged by herbicides and insecticides in many ways. One is indicated by irregular spots emerging on the leaves as if parched. At the beginning the spots are yellowish white and later change to reddish brown. The damaged parts and the unaffected parts are clearly separate. The damaged parts do not spread but the entire leaf may wither when affected seriously. The damage is caused mainly by an unabalanced application of herbicides or overly concentrated herbicides. Another type of damage is manifested by yellowing of the leaves or yellowing of the entire plant. When the plant is seriously affected, the plant withers and dies. The cause of such damage is mainly due to an application of over doses of such chemicals as 666 (BCH or benzene hexachloride) and jialiufen (methyl arsinic calcium). The third type of damage is manifested by dwarfing of the affected plant. The color of the leaves is black-green. The blades of the leaves harden. When seriously affected, deformed leaves like "onion tubes" emerge. This damage is mainly caused by over concentrations of such weeding chemicals as 2,4-D dimethyl tetrachloride. The fourth type of damage is the

formation of deformed panicles. Affected plants remain green up to the time of maturation. The weight of grains drops and semi-filled grains increase or in other cases panicles do not head and the plant remains dark green or deformed panicles head with twisted branches and degenerated spikelets form. Germination may occur on the panicles or several grains may grow together and 6 to 7 glumes may emerge like pedals of flowers. This damage is mainly caused by the application of organic arsenic chemicals such as zinc methan arsonate and daoning between the period of panicle bearing and the early period of filling.

I. Damage by Fertilizers

Parching by ammonia water or ammonium hydrocarbonate: Ammonia water or ammonium hydrocarbonate are unstable. Under high temperatures, when the field lacks water or when the concentration in a localized area is too high, ammonia is released and parches the leaves of the paddy rice plant. Mostly affected are the lower leaves. At first they appear dark green but the color of the entire leaf changes to orange. The leaves are erect at a 45° angle and finally the color of the leaves turns brown and die. If granules of ammonium hydrocarbonate attach themselves to the surface of the leaves, purplish brown spots will occur.

Parching by ammonium sulphide: Ammonium sulphide may remain on the surface of the leaves when applied in the morning or after a rainfall while there are drops of water on the leaves of paddy rice. An overly high concentration in localized regions will cause the leaves to undergo reverse filtration and the leaves will be parched. Affected leaves manifest irregular white and transparent spots.

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